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EDITORIAL NOTES.

IT is with very great regret that the Editors find themselves compelled to announce to their friends and subscribers that a crisis has arisen in the affairs of the GEOLOGICAL MAGAZINE, gravely imperilling its future existence. For some years past the Magazine has been conducted on an extremely narrow margin between profit and actual loss, and now, owing to a further sudden rise in the cost of production, the former trivial, almost negligible, profit will be converted into a considerable loss on next year's working unless some further economic steps are taken. The whole situation has been most carefully considered between Editors, publishers, and printers, and certain minor adjustments are suggested in connexion with business arrangements. As to these it is not necessary to enter into detail here. But these measures of economy alone would be quite inadequate to make up the deficit: some considerable increase of revenue is indispensable, and the only possible source for this is an increase in the price of the Magazine. The sole alternative is to cease publication at the end of the present volume. The Editors feel, however, it is hoped without undue egotism, that this course would be a serious blow to the science of geology, and after long and anxious consideration they have decided to raise the price of the Magazine as from January next to 2*s*. 6*d*. per copy or 30*s*. per annum. In taking this step they are compelled to rely on the loyalty of friends and subscribers, and feel confident that this trust will not be misplaced. The Editors venture to appeal most earnestly to present subscribers to continue their subscriptions, and to use every effort in their power to obtain fresh support, so that the GEOLOGICAL MAGAZINE may be enabled to continue unbroken its career, which it is hoped and believed has been one of usefulness and honourable effort in the cause of progress in geology. The Editors on their part will spare no effort to maintain the traditions of the past, and by strict attention to business to carry on the Magazine through the period of storm and stress, which is perhaps only of a temporary nature. Such is the present situation: the future rests with our readers.

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WE understand that the department that was set up by the Ministry of Munitions early in 1917 for the development of the mineral resources of this country, in the first instance under the control of Sir Lionel Phillips, has been taken over by the Board of Trade, and will be continued as a branch of its Industries and Manufactures Department under the care of Dr. F. H. Hatch.

"After three years of anxiety and stress," says Sir Charles Parsons, the President, at the Bournemouth Meeting of the British Association, the meetings for the intervening years having been cancelled, the Association accepted the renewed invitation of friends and colleagues to Bournemouth for September 9–12, 1919. The President (after referring to the critical time of the meeting, when after the great upheaval the elemental conditions of organization of the world are still in flux) pointed out in what way the British Association could best assist in the great work of reconstruction and progress now lying before us. (1) By requisitioning and printing reports on the present state of different branches of science; (2) by granting sums of money to small committees or individuals to enable them to carry on new researches; (3) by recommending the Government to undertake expeditions of discovery, or to make grants of money for certain national purposes, which were beyond the means of the Association. [As a matter of fact it has, since its commencement, paid out of its own funds upwards of £80,000 in grants of this kind.]

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He proceeded to discourse on some of the developments in engineering during the period prior to the War, in engines and turbines, in Naval architecture, on tungsten steel, on gaseous explosions, on the science of war, the advance in artillery and aircraft, on sound-ranging and listening devices, and on electricity. The President referred to the problems of the future, especially on the relative cost of producing a given amount of electrical power from coal and from water-power. It is estimated that the average capital required to produce electrical power from coal is less than half the amount that is required in the case of water-power; but the running costs in connexion with water-power are much less than those in respect of coal. The cost of harnessing all the water-power of the world would be about 8,000 millions, or equal to the cost of the War to England.

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Sir Charles devoted the penultimate section of his address to borehole projects (which he had studied in 1904). He proposed to sink a shaft 12 miles in depth—about ten times the depth of any shaft in existence. The estimated cost was £5,000,000, and the time required about eighty-five years, a period not often reached in one lifetime! One question raised was: would the rocks at this great depth crush in and destroy the shaft? Professor Frank Adams, of McGill College, Montreal, published some results of his experiments on crush-strains on rocks in the *Journal of Geology*, 1912, from which he estimated that in limestone a depth of 15 miles would probably be practicable, and in granite a depth of 30 miles might be reached. Little is at present known of the earth's interior except by inference from a study of its surface, upturned strata, shallow shafts, the velocity of transmission of seismic disturbances, its rigidity and specific gravity. Some attempt, he suggests, should be made to sink a shaft as deep as may be found practicable at some locality selected by geologists as the most likely to afford useful information. In Italy, at Lardarello, boreholes have been sunk, which discharge

large volumes of high-pressure steam, which is being utilized to generate about 10,000 horse-power by turbines. At Solfatara, near Naples, a similar project is on foot to supply power to the great works in the district. It seems, indeed, probable that in volcanic regions a very large amount of power may be, in the future, obtained directly or indirectly by boring into the earth, and that the whole subject merits the most careful consideration.

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From motives of strict economy in printing and paper on the part of the Treasury, the Annual Reports of the Keepers of the various Departments in the British Museum which accompany the Return of Receipts and Expenditure presented to the House of Commons have been reserved to a future and more prosperous time. The statement relating to the British Museum, Bloomsbury, shows the precautions taken to protect the collections from air-raids, etc., in 1916–18, and the parts, still closed to the public, lent to the Registry of Friendly Societies. Precautions were also taken to protect the most choice specimens in Bloomsbury and in the Galleries of the Natural History Departments at Cromwell Road, but with the exception of the Northern Galleries of Geology all the exhibits in the latter building were open, and the public have been admitted on week-days from 10 till 4 o'clock. An exhibition of the boring Mollusca and Crustacea destroying wood and stone, and those attached to piers and ships below the water-line, has been arranged by Dr. W. T. Calman for Government and public information. Reports have also been prepared on Fishes valuable as food, and on the utilization of whale-flesh. The preservation of elephant seals and the reintroduction of fur-seals, also the acclimatization of the reindeer in South Georgia, are instances in which scientific advice has been afforded to Government by the Museum staff.

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Mrs. Hinde has presented to the Geological Department the valuable collection of fossils, chiefly from the Silurian and Ordovician rocks of Canada, the United States, and Sweden, made by the late Dr. George J. Hinde, F.R.S., together with his unique series of microscopic preparations of rocks and fossils.

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The Royal Microscopical Society have given 1,000 slides of samples of "oozes", spread over the ocean-floor at great depths, collected by the late Dr. G. C. Wallich, and an additional series from Mr. E. Heron-Allen, F.R.S., with maps and charts.

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A large collection of fossil shells and vertebrate remains from the Ameki cuttings on the Port Harcourt Railway, Southern Nigeria, have been presented by Mr. A. E. Kitson, Director of the Geological Survey of the Gold Coast.

ORIGINAL ARTICLES.

I.—A Remarkable Carboniferous Coral.

By R. G. Carruthers, F.G.S., Geological Survey of Scotland.

(PLATE XI.)

AMONGST the Carboniferous corals, not the least interesting are those species which, for one reason or another, may be difficult to classify, or at any rate diverge somewhat from the common order. It is with one of these aberrant members that the present communication is concerned; and it is, perhaps, not altogether unfitting that most of the material happens to be of Irish origin.

The peculiarities under review are essentially of a developmental nature: as a preliminary, therefore, it is as well, even at the risk of needless repetition, to outline the normal order of septal development characteristic of the Rugosa in general.

Fig 1

Fig 2

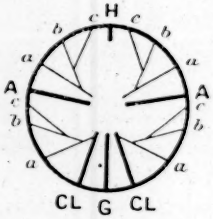


Fig 3

Fig 4

Fig 5

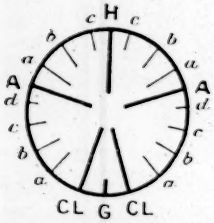


Fig 6

Development of the major septa in a normal Rugose Coral (Figs. 1–3) and *Cryptophyllum* (Figs. 4–6). H, main or cardinal septum; A, alar septum; CL, counter-lateral septum; G, counter septum; *a*, *b*, *c*, etc., metasepta.

The initial growth-stages of a Rugose coral are frequently obscured, for it is obvious that if the basis of attachment be relatively large there will be a corresponding increase in the number of septa first seen. In the most favourable circumstances, the first stage shows a single septum (the "axial septum") stretching across the diameter of the corallum from wall to wall (Diagram, Fig. 1); later on this separates into the main and counter primaries, opposite one another. At each end of the axial septum a pair of new septa then appear,

which eventually become the alar and the counter-lateral primaries (A and CL in Diagram, Fig. 2). One of these pairs may precede the other, or they may appear simultaneously, but in any case they move outwards until approximate symmetry is attained; the primary stages, resulting in the formation of six septa, are then complete (Diagram, Fig. 2). All subsequent major septa ("metasepta" is the convenient term for them proposed by Duerden) are inserted according to an invariable rule: in the two "main" sectors H–A (Diagram, Fig. 3) the newest are those next to the main septum H, in the alar sectors A–CL they are next to the alar primaries A, in the counter-lateral sectors CL–G none ever appear. From this results the well-known pinnate disposition of the septa seen after removing the epitheca from the conical portion of a Rugose coral (the part, that is, wherein there is a continuous addition of new septa).

In addition to the major septa, many species have a cycle of *minor septa*. These are relatively short and are most often a feature of adult growth-stages. They appear simultaneously, one between each major septum, those in the two counter-lateral sectors CL–G often being longer than the others: sometimes there are two minor septa only, in which case they are restricted to the two counter-lateral sectors, one on each side of the counter-primary G. Where seen, this factor is of much value in the orientation of transverse sections.

The foregoing scheme of septal development is applicable to all manner of Rugose corals, but in the genus *Cryptophyllum*, now under review, it is very curiously modified.

Development of *Cryptophyllum*.

Cryptophyllum hibernicum is a small solitary coral, tortuous in habit, with a smooth concentrically ribbed epitheca (Pl. XI, Fig. 5). It is easy to distinguish from other Carboniferous corals, immature specimens displaying five septa only, while even in adults these five septa remain predominant (Pl. XI, Figs. 1*f*, 2*c*, 3*h*). The special developmental features of the genus are easily followed in a set of serial transverse sections.

Very commonly there are no traces of septa whatever in the earliest growth stages, the corallum being purely tabular (Pl. XI, Fig. 1*a*). Later on septa appear, initially as minute protuberances from the wall, each with a dark centre (Pl. XI, Fig. 1*b*): generally they increase in length until five septa are formed, meeting in the centre of the corallum (Pl. XI, Figs. 1*f* and 3*f*). These five septa are not inserted in any regular order, and they are frequently affected by growth-constrictions (or "rejuvenescence") of the corallum, leading to a retraction or even obliteration of one or more of their number (cf. Figs. 3*c* and 3*d*, Pl. XI): not infrequently, the rejuvenescence is so extreme that a resumption of the tabular, non-septal condition is brought about. Eventually, however, the five-septal stage is established on a more or less stable footing, and may persist for some time. It has been arrived at, as we have seen, in an altogether hesitating, wayward manner, and is so unlike anything seen in the early stages of normal Rugose corals that were no further evidence available, one might justifiably suspect that an entirely new order was under

observation. From now onwards, however, the addition of new septa follows a definite plan. Let the five-septal stage be provisionally regarded as primary: on inspection it will be noticed that two of the septa are set out from the epitheca more closely than the rest (i.e. those lettered CL in Figs. 1*f* and 3*f*, Pl. XI), an arrangement emphasized in later stages. Using the terminology applied to normal Rugosa, these two septa, throughout the metaseptal stages, behave as if they were the counter-lateral primaries, the septum directly opposite as if it were the main (or cardinal) septum, the remaining two as if they were the two alar primaries (cf. Diagram and Pl. XI); that is to say, once the five-septal stage is completed, of all septa appearing in the sectors A–H the last-formed is the one nearest to what, for the sake of argument, has been termed the main septum H; in the two sectors A–CL the youngest septum is the one closest to A.[1] It is obvious that such an arrangement is strictly in accordance with that governing the insertion of metasepta for the Rugosa in general. This is satisfactory enough, but there still remains one respect in which *Cryptophyllum* shows a remarkable divergence from the normal. It will be seen, on referring to the serial transverse sections 1*a*–1*f*, Pl. XI, that in not one of these, not even in those of the final growth stages, can any trace of a counter primary septum be detected: yet in other Rugose corals, this would have been present throughout, from the earliest stages onwards. The omission is at first puzzling, but a clue is obtained in the next set of serial sections (Pl. XI, Figs. 3*a*–3*h*), cut from what is apparently a more advanced type: here, in the final section, 3*h*, a single septum (lettered G), relatively small, at last appears between the two counter-laterals CL. The same thing happens in another set of serials (Pl. XI, Figs. 2*a*–2*e*).

The conclusion that the septum which appears so tardily between the two most closely approximated of the five primaries of *Cryptophyllum*, is in reality the missing counter-primary, is confirmed by the study of one more set of serials (Pl. XI, 4*a*–*d*). In these it will be noticed that in the final growth-stage (Fig. 4*d*) two new septa, quite small, have come in, one on each side of the "counter septum". In an early paragraph of this paper, it will be remembered that when commenting on the scheme of septal development characteristic of Rugose corals it was stated that the minor septa "are relatively short, and are most often a feature of adult growth-stages", and that "sometimes there are two minor septa only, in which case they are restricted to the two counter-lateral sectors, one on each side of the counter-primary G". If, therefore, the two small septa, one on each side of G in Fig. 4*d*, Pl. XI, be regarded as minor septa (which their appearance at such a late growth-stage would indicate), all difficulties vanish: their development agrees with that characteristic of minor septa in other Rugose corals, and supports the conclusion arrived at on other grounds, that the septum G is in reality the counter-primary.

[1] Naturally this cannot be fully demonstrated in the sections figured, but it has been confirmed by the examination of specimens from which the epitheca was removed by acid.

Specimens of *Cryptophyllum* showing anything in the nature of minor septa are not very common ; in the few cases I have observed two septa only were found, developed exactly as in the foregoing example.

Summing up, one may say that *Cryptophyllum* may be classed with the Rugose corals, with the reservation that the development of the primary septa is quite abnormal, for the counter-primary is either altogether absent or else does not appear till a relatively late period. Resulting from this, a stage with five septa only, all primary, is a marked feature of the genus: these five septa are inserted in an irregular manner, but once established usually remain prominent throughout the remaining growth-stages. The development of both metasepta and minor septa proceeds exactly as in other Rugose corals.

Formal diagnoses, with remarks on distribution, affinities, etc., are appended below.

Genus Cryptophyllum, gen. nov.

Diagnosis.—Corallum simple. Five septa, all primary, but variable in sequence, appear before the others, and remain predominant until the growth of the corallum is completed : their disposition is not quite symmetrical, two (the counter-lateral primaries) being closer than the others. The remaining primary (the counter septum) appears subsequently, or may be entirely absent. The development scheme of both metasepta and minor septa (if any) agrees with that of other Rugose corals. There are tabulæ, but no dissepiments.

Affinities.—Several genera bear a superficial resemblance to *Cryptophyllum*. In 1872 de Koninck[1] proposed *Pentaphyllum* for a genus with five septa much more developed than the rest. Two species were described and figured, *P. armatum* and *P. caryophyllatum*, both from the Carboniferous Limestone of Tournai ; but in the course of a visit to the Musée d'Histoire Naturelle at Brussels many years ago I was unable to find the originals. The species first dealt with by de Koninck (and presumably, therefore, his genotype) is *P. armatum :* the epitheca is covered with spinose outgrowths, well portrayed in one of the figures (*loc. cit.*, pl. iv, fig. 8), but with regard to the septa the illustrations are at variance with the text : in his Plate, Fig. 8*a* shows six, not five, leading septa, three at right angles to one another, the remainder closely approximated : the species appears to be a spinose Zaphrentid or Campophyllid. In the case of *P. caryophyllatum*, the figure of the calyx (*loc. cit.*, pl. iv, fig. 9*a*) again differs from the text, four leading septa only being shown. The discussion need not be carried further, for Dr. G. J. Hinde, while noting the conflict between the text and figures of de Koninck, has pointed out that the name *Pentaphyllum* was pre-occupied in 1821 for a genus of Coleoptera.[2] At the same time, he

[1] de Koninck, *Nouv. Recbs. anim. foss. terr. carb. Belgique*, p. 58, Brussels, 1872.

[2] G. J. Hinde, "Notes on the Palæontology of Western Australia" : Geol. Mag., 1890, p. 195.

proposed *Plerophyllum* for a somewhat similar group of Australian corals, and in his diagnosis (*loc. cit.*, p. 195) states that "there are usually five prominently developed septa (in some species only four). . . . In the species with five prominent septa, the cardinal septum is small and is bounded on either side by a large septum, and the remaining three large septa represent the alar and counter septa". A pronounced stereoplasmic thickening of structures within the body of the coral is noted as one of the generic characters. This latter feature is known to be a most variable quantity in other genera, but the septal arrangement alone is a sufficient distinction from *Cryptophyllum*, in which the main (or cardinal) septum is long, with no prominent septa on either side, and the counter primary is often absent altogether: the orientation, in fact, is reversed. Judging from Dr. Hinde's figures (*loc. cit.*, pl. viii*a*, figs. 1*a–f*), I am inclined to agree with Mr. Etheridge[1] that *Plerophyllum* should rather be classed as a sub-genus of *Zaphrentis*: it has much in common with such forms as *Zaphrentis* (*Lophophyllum* auctt.) *eruca* (M'Coy).

The Lower Palæozoic genera *Anisophyllum* and *Baryphyllum* of Milne-Edwards and Haime have only three prominent septa.

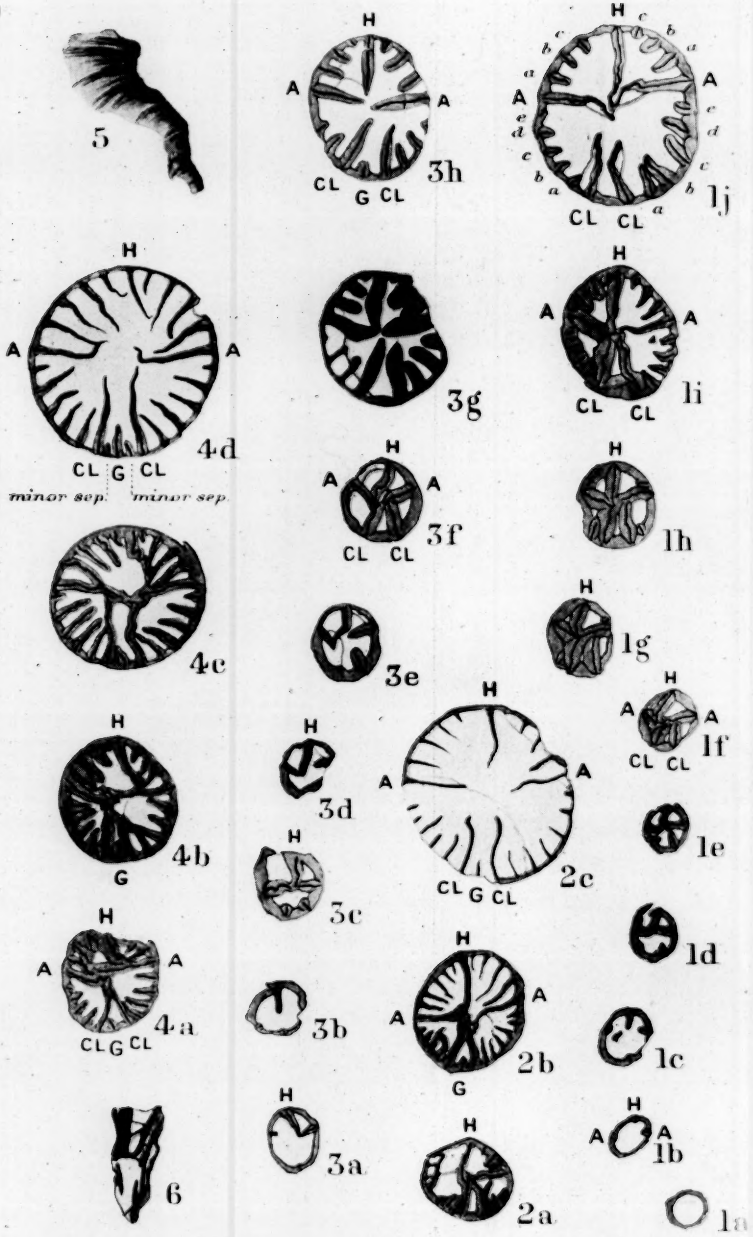
Sections of *Caninia cornucopiæ* sometimes have a superficial resemblance to Fig. 4*c*, Pl. XI of this paper, but there is no risk of confusion if attention be paid to the orientation and nomenclature of the septa, which is entirely different in *Cryptophyllum*, quite apart from the profound distinctions of the primary stages.

CRYPTOPHYLLUM HIBERNICUM, *sp. nov.*

Diagnosis.—Corallum simple and averaging an inch or less in length: a tortuous habit is common. Strong, smooth epitheca, with frequent growth-lines and constrictions (Pl. XI, Fig. 5). Major septa stout, tapering at their inner ends, frequently wavy and irregular in cross-section. The first five septa are all primary: their development shows much individual variation, but they remain longer and more conspicuous than other septa throughout the life-history of the corallum: it is only in the gerontic period, when, as with so many other Carboniferous corals, an amplexoid type of septation is approached, that there is any difficulty in singling out the five primaries from the rest. The sixth primary, the *counter septum*, does not appear until several metasepta have developed, and may be absent altogether. The metasepta themselves are relatively short. As a rule there are no minor septa: if present, they are two only, one on each side of the counter primary: they are rudimentary, and confined to the final growth-stages. A stereoplasmic thickening of the septa below the calyx is common, but it is not so pronounced as to fill in the body of the coral. The tabulæ are few and irregular (Pl. XI, Fig. 6).

Remarks.—Referring to Plate XI, illustrating this paper, the fact that the serials 2*a*–2*c* and 4*a*–4*d* show an earlier appearance of the

[1] R. Etheridge, *A Monograph of the Carboniferous and Permo-Carboniferous Invertebrata of New South Wales*, pt. I, Cœlenterata, p. 8. Mem. Geol. Surv. New South Wales, Sydney, 1891.



R. G. C. del. S. Austin & Sons, Ltd. Imp.

CRYPTOPHYLLUM HIBERNICUM, GEN. ET SP. NOV.

counter-primary than in the set 1*a*–1*i* or 3*a*–3*h* suggests a more advanced type, for which separation may eventually be desirable; while noting this possibility, it is thought better, for the present, to refer all the figured examples to one species only.

Distribution.—*Cryptophyllum hibernicum* is locally abundant along a bed of limy shale, 3 or 4 inches thick, towards the base of the Lower Calp Shales at Bundoran, Donegal Bay, Ireland: the best exposures are in the sea cliff immediately north of the Bradoge River. Associated fossils are *Caninia cornucopiæ* and *Cyathaxonia cornu*, and in terms of Dr. Vaughan's zones the horizon approximates to C_2–S_1, locally developed as a γ phase.

In the Geological Survey Collections, London, amongst an extensive suite of Upper Tournaisian corals procured by Mr. Pringle, on the Pembrokeshire coast of Stackpole Quay, and near Blucks Pool, four specimens of *Cryptophyllum hibernicum* were noticed. The horizons given by Mr. Pringle range from Z_2 through γ to C_1: in all cases *Caninia cornucopiæ*, *Cyathaxonia cornu*, and the gens of *Zaph. omaliusi* were found in association.[1]

In Scotland, small, immature examples of *Cryptophyllum* are not uncommon in the shale above the Middle Skateraw Limestone at East Barns Quarry, Dunbar. One or two have also been obtained from the shale above the Acre Limestone at Ancroft, Northumberlandshire, which is probably on the same horizon. At both localities *Caninia cornucopiæ* (practically identical with Tournaisian specimens) *Cyathaxonia cornu*, and Zaphrentids of the *omaliusi* gens are associated in abundance. Zonally the level is about D_2. None of the specimens are fully developed: they rarely get beyond the five-septal stage, but so far as can be seen agree perfectly with *C. hibernicum*.

It will be noted that the vertical range of the species is wide, and it is probably safe to say that *C. hibernicum* may be expected whenever a γ phase is met with in British Carboniferous Limestone rocks.

In concluding this paper, I wish to express my indebtedness to my colleague Dr. G. W. Lee, of the Geological Survey of Scotland, and to Mr. W. B. Wright, of the Geological Survey of Ireland: their assistance in the collection of specimens, during a joint examination of the Bundoran sections, proved invaluable. Dr. W. D. Lang, of the British Museum (Natural History), has very kindly helped me in the matter of nomenclature.

EXPLANATION OF PLATE XI.

Reductions of camera-lucida drawings of *Cryptophyllum hibernicum*, gen. et sp. nov., from the Lower Calp Shales (Carboniferous Limestone) of Bundoran, Donegal Bay, Ireland: intersections of tabulæ are omitted in one or two cases where they interfere with a clear presentation of the septa.

Figs. 1*a*–*j*, 2*a*–*c*, 3*a*–*h*, 4*a*–*d*: serial transverse sections from four specimens. × 2½. Index to lettering: H, main or cardinal septum; G, counter septum; A, alar septum; CL, counter-lateral septum.

Fig. 5. External aspect of an average specimen. Nat. size.

Fig. 6. Vertical section, showing tabulæ. Nat. size.

[1] The registered numbers are Pg. 1715, Pl. 928, Pl. 2339, and Pl. 2432, and particulars of the exact localty are given in the Survey records.

II.—Morphological Studies on the Echinoidea Holectypoida and their Allies.

By Herbert L. Hawkins, M.Sc., F.G.S., Lecturer in Geology, University College, Reading.

IX.—*Pyrina*, *Conulus*, and *Echinonëus*.

THE three genera (or generic terms) that serve for the title of this paper comprise a series of Cretaceous and Tertiary Echinoids which are morphologically similar, and, in consequence, systematically chaotic. Although the time is not yet ripe for an attempt to disentangle the nomenclature of the various genera and species from the knot in which it is involved (a condition not to be wondered at in view of the early description and variable qualities of the forms), it seems desirable to publish the following comments on the group, making use of current names for the examples quoted. *Pyrina*, Desmoulins, as Lambert[1] has shown, is typified by *P. petrocoriensis*, Desm., a species that might well pass for a young member of the *Conulus* series. *Conulus*, Leske, has for genotype *C. albogalerus*, Leske, and the forms to which that name is usually applied in this country seem sufficiently like the original figure to pass muster. The genotype of *Echinonëus* is of course *E. cyclostomus*, Leske, and there has never been serious confusion as to the application of the generic name.

Under the name *Galerites*, Lamarck, *Conulus* became extended to cover practically all the Holectypoida, and to include considerable numbers of Clypeastrids and Echinolampids; but the original type has always been correctly placed, either under one of the two foregoing names or that of *Echinoconus*. *Pyrina* was more than usually unfortunate in the series of species included in it by its author. Of the seven species cited by Desmoulins, *P. petrocoriensis* is the only one that is either recognizable or conformable to the diagnosis, although another (*Nucleolites ovulum*, Lamarck) is almost, if not quite, admissible. The long rejected *Globator*, Agassiz, 1840, has been revived (with subgeneric rank) by Lambert (l.c.), and the latter author has proposed the name *Pseudopyrina* for the large number of more or less ovoid Echinoids that have usually been placed in *Pyrina*. Before proceeding to analyse the morphological qualities of the genera, a brief comment on this proposed taxonomy is necessary.

Lambert (l.c., p. 141) shows that Desmoulins, in founding the genus *Pyrina*, twice emphasized the "symmetrical" character of the peristome, and even proposed to exclude *Nucleolites ovulum*, Lam., because of the slight obliquity of the peristome in that species. Further, *Pyrina* had a perignathic girdle ("système buccal interne") analogous to that of *Galerites* (*Conulus*). It may be remarked that in Desmoulins' time, and for long afterwards, the belief was always maintained that the possession of masticatory apparatus (including the perignathic girdle) was restricted to Echinoids with "symmetrical" (i.e. circular, pentagonal, or decagonal) peristomes. Unfortunately for this belief, however, *Conulus* itself, which has a perignathic girdle

[1] "Étude sur les Echinides crétacés de Rennes-les-Bains et des Corbières": Bull. Soc. Études Sci. Aude, vol. xxii, pp. 66–183, pls. i–iii, 1911.

in large, though peculiar, development, has an undoubtedly oblique peristome. In *C. rhotomagensis*, *C. castanea*, and *C. subrotundus* this character is quite marked; it is less clear in *C. albogalerus*, but among hundreds of specimens (of very varying shapes and sizes) that have passed through my hands, every one has shown appreciable ellipticity of the peristome. *Echinonëus*, in spite of the unfortunate name of its genotype, has a strongly oblique peristome when adult. As far as my experience goes, I am convinced that the "obliquity" or "symmetry" of the peristome are merely relative in all the forms usually comprised under the three names in the title. Lambert says of *P. petrocoriensis* that its peristome "est en effet semblable à celui des *Conulus*"—that is to say, it must be slightly oblique. If this is so, why should not *Nucleolites ovulum*, Lam., whose peristome is slightly more oblique, be admitted into the genus? A yet more marked obliquity characterizes the peristome of *P. desmoulinsi*, d'Arch., but the difference is merely one of degree. The species last named has a "système buccal interne" sufficiently "analogue à celui de" *Conulus*. I have not succeeded in dissecting out the girdle of *P. desmoulinsi*, but by sectioning a test and its infilling matrix I have determined that a raised and thickened rim surrounds the peristome within. It has yet to be suggested that *Conulus subrotundus* and *C. albogalerus* are not congeneric, but I have studied undoubted examples of the former species in which the peristome was no less oblique than it is in *P. desmoulinsi*, or, for that matter, in *Trematopygus*. But if these two common species of *Conulus* are to be allowed to share the same generic name, it seems illogical to attempt a separation of the various species commonly called *Pyrina* on the ground of variable obliquity of the peristome. That there may be other features that would warrant the generic distinction of some of the species I am prepared to admit, but *Pseudopyrina* seems to me to be based on false premisses and so unacceptable.

Globator, with type *G. nucleus*, Agassiz, included a series of forms (with relatively pronounced peristomial obliquity) that may be roughly described as "roundish *Pyrinas*". *G. nucleus* is always a little longer than broad, and a little less in height, but it is at least as "regular" in shape as, say, *Holectypus depressus* or many forms of *Conulus subrotundus*. Certainly the difference in ambital outline between *Globator* and such a species as *Pyrina desmoulinsi* is very marked, but all possible gradations link the two species, and the species of *Conulus* vary but very little less in this respect. If the globular character can be shown to have any phyletic, or even stratigraphic, meaning, *Globator* might be recognized as a valid genus, but I am unaware that either quality has been demonstrated.

As a consequence of the arguments given above, I prefer to follow the old-fashioned, and apparently natural, use of the name *Pyrina*, and to include in it as unnecessary or unsubstantiated groups the two so-called genera *Globator* and *Pseudopyrina*. In passing, it seems advisable to draw attention to a statement made by Lambert (l.c., pp. 142–3) concerning *Pyrina houzeaui*, Cotteau. "In spite of the presence in this circular species of a small, imperforate, fifth genital," Lambert does not feel justified in separating it from *Globator* (i.e.

Pyrina). It is perhaps reasonable to complain of the laxity of Agassiz, Desor, and de Loriol in not allowing sufficient weight to the characters of the peristome, but surely the apical system deserves a little notice. If there is one constant feature that differentiates the *Pyrina–Conulus–Echinonëus* series from the other Holectypoida, it is the absence of a posterior genital plate. All three genera have almost identical apical systems, and to admit a species that *normally* differs in so important a character as the presence of an additional plate is to subvert taxonomy. However, there is at least a possibility that the "small, imperforate, fifth genital" of *P. houzeaui* may be an individual variant, even if it has any real existence. Such supplementary plates do occur occasionally in the apex of *Conulus*, presumably as expressions of regressive variation, and cases have not been wanting when a fifth genital has been ascribed to that genus as a normal feature. Lambert (l.c.) corrects the figure of the apical system of *Globator nucleus* given by Desor, stating that the fifth, imperforate genital *does not exist*. However (p. 149), he refers to a "rudiment of the fifth genital" as occurring between the posterior oculars in *Pyrina atacina* (*atacica*, Cotteau), but it is not clear whether his description is based on one specimen or is a generalization. If this is a normal feature in the species, it constitutes not merely a morphogenetic point of the utmost interest, but, to my mind, a reasonably sound basis for generic separation. However, at present I incline to regard the occurrence of posterior genitals in these forms as individual variants, interesting and instructive, but abnormal.

The foregoing paragraphs are intended to explain the meaning here attached to the three generic terms used as the title of the paper. That further subdivision of *Pyrina* and *Conulus* will prove necessary in the future I not only expect, but believe; but for the present they serve as well-marked, though closely similar, genera. It is important to lay stress upon the striking resemblances that all three types show to one another, since it is usual and orthodox to admit *Conulus* into the Holectypoida, and to relegate *Pyrina* and *Echinonëus* to the Spatangoida. One purpose of the present paper is to contend that the three genera are too closely related to be separated by even family distinction, and that the ruling of an ordinal line through the group is unnatural.

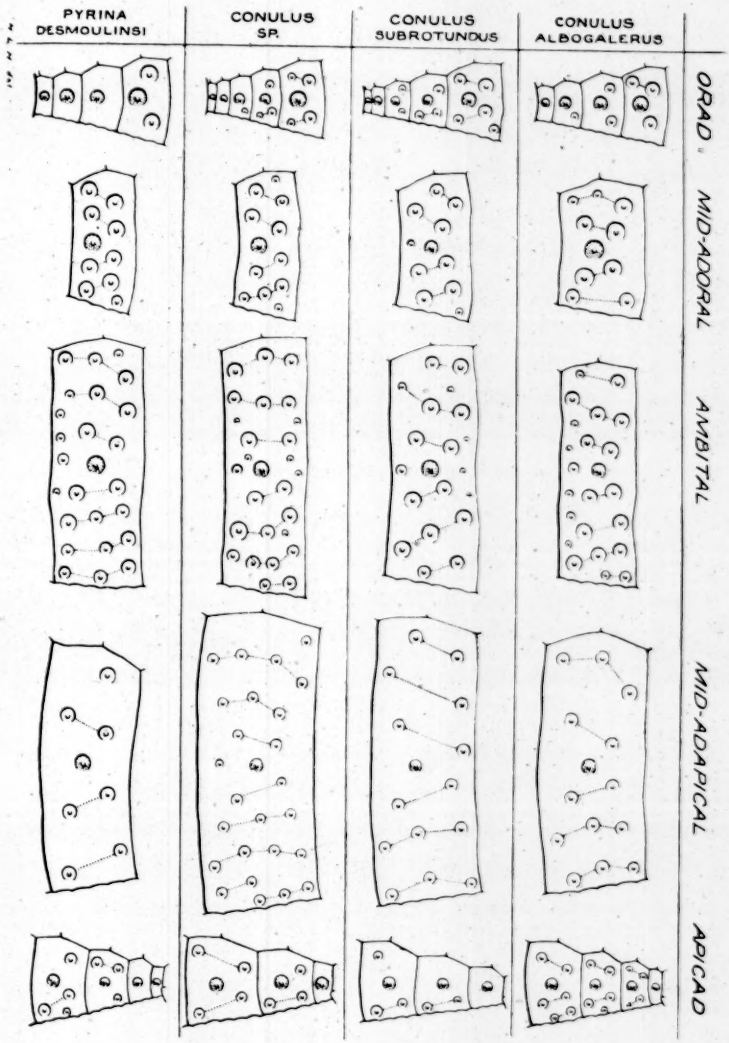
The following are the chief morphological resemblances:—

Shape.—Antero-posterior diameter always greater than transverse. The degree of elongation of the test varies much within the genera, but the two diameters never become quite equal, save perhaps in very young examples. Height extremely variable, usually less than the transverse diameter except in late species of *Conulus*.

Peristome.—Always to some degree oblique, elongated approximately on the axis II, 4. The obliquity is most marked in *Echinonëus*, where, however, the peristome of the young is almost perfectly symmetrical (decagonal).

Perignathic girdle.—Discontinuous, strongly inclined, and well buttressed in *Conulus*, apparently similar in *Pyrina*, but wholly wanting in adult *Echinonëus*, where the vestigial girdle of the young is very imperfectly developed.

Periproct.—Ovoid or elliptical, comparable with the peristome in area. Supra-marginal, or on a posterior surface, in *Pyrina*, marginal in *Conulus*, infra-marginal in *Echinonëus*. (In young forms of *Conulus* it may be as high as, or higher than, in adult *Pyrina*.)



Analysis of interambulacral tuberculation in *Pyrina* and *Conulus*.

Apical system.—Squarish in outline, built normally of four genitals (the madreporic one being the largest) and five oculars, of which the three anterior plates are minute, while the two posterior ones are

transversely elongate, and by their meeting form the entire posterior margin of the system. The proportions and disposition of the nine plates are practically identical in all three genera.

Ambulacra.—Narrow and lanceolate, with narrow pore-fields and relatively wide, thickly ornamented, perradial tracts. Pores similar throughout, constantly minute; completely uniserial except near the peristome in *Conulus*. Plates grouped in threes, comparable with the "Echinoid" type of triads (Duncan), practically throughout the areas. There is never more than one demi-plate in a group, however reduced in height the smaller primary may become. Ornament similar in character to that of the interambulacra, very regularly distributed as far as concerns the main tubercles.

Interambulacra.—Relatively broad, built of fairly low, usually bent, plates thickly covered with ornament. Primary tubercles well-scrobiculate (especially near the ambitus and adorally), arranged in a definite sequence. The central series in each column is not sensibly different from the rest except in position. Adradially and interradially the other series are developed in more or less distinct chevron pattern. The tubercles are perforate in *Pyrina* and *Conulus*, imperforate in *Echinonëus*. Smaller ornament profuse and very diverse in character, always including "glassy tubercles".

Excluding variation in the shape of the test (which is probably due to the influence of surroundings and consequent mode of life), the differences that exist between the three genera can be regarded as of two kinds. The position of the periproct changes in a direct sequence chronologically, since *Pyrina* is the first of the three to appear and *Echinonëus* the last. The nature of the change is very suggestive of evolution along a line parallel to that which led from *Plesiechinus*, through *Holectypus* to *Discoidea*, and to that proved in the ontogeny of several Spatangoids. Curiously enough, the other features of difference do not seem to follow the same sequence. The perignathic girdle of *Conulus* is more massive than that of *Pyrina* (though the greater thickness of the test in the former may perhaps in part account for this), while it is completely absent from the adult *Echinonëus*. From *Pyrina* to *Echinonëus* the sequence is maintained, but *Conulus* fails to take its place in the series in this respect. Again, in the matter of the ambulacra, *Conulus* has strongly triserial (almost phyllodal) pore-pairs near the peristome, while in *Pyrina* and *Echinonëus* simplicity is retained throughout. In interambulacral ornament *Pyrina* and *Conulus* agree in the perforation of the tubercles, but all three genera are alike (save for details) in the order in which the tubercles are grouped on the plates. It is interesting to note that, by the often bewildering confusion of its tuberculation, *Conulus* is slightly less "Holectypoid" than the other two genera, whereas its differences from them in other points seem all to trend towards the true Holectypoid characters. Regularity of tubercle sequence is a diagnostic feature in the order, and is not met with in the adults of any other kinds of Irregular Echinoids—that is, if *Pyrina* and *Echinonëus* are admitted into the Holectypoid fold. It can always be recognized in *Conulus*, but in some species, notably *C. castanea* and large examples of *C. subrotundus*, it is very difficult to trace.

It appears, then, that *Conulus* is rightly regarded as an Holectypoid, although its tuberculation brings it dangerously near the border-line: while *Pyrina* and *Echinonëus* differ from the normal character of the order merely in shape (a purely relative and very variable quality, as "*Globator*" shows) and in the absence of any marked triserial arrangement of the orad pore-pairs. The latter feature can be fairly regarded as the successful completion of the tendency towards podial simplification that is persistent in the order. If it is admitted that the resemblances between the three genera are so many that they must surely be closely related in phylogeny, the two insignificant items in the construction of *Pyrina* and *Echinonëus* cannot be permitted to exclude them from the Holectypoida.

That *Echinonëus* is practically a lineal descendant from *Pyrina* seems evident. The *Pyrina* group ranges through the Cretaceous, and species of *Echinonëus* are restricted to the Tertiary. Save for the position of the periproct and the perforation of the tubercles, there is little difference between the two that could warrant their distinction even as genera. Periproct position points to *Conulus* as a transitional stage from one to the other, but no other morphological features support that indication. It is true that *Conulus* occurs chiefly in the Upper Cretaceous, and is definitely of later origin than *Pyrina*, but its peculiar characteristics make it impossible to believe that *Pyrina–Conulus–Echinonëus* represents a genetic series. To suggest that *Conulus–Pyrina–Echinonëus* is the true sequence seems more plausible, since *Conulus* is an accredited Holectypoid, while *Pyrina* and *Echinonëus* are much alike and usually considered to be Spatangoids. But there are insuperable difficulties in the way of acceptance of such a hypothetical line of evolution. In the first place, it violates the known stratigraphical order of appearance of the forms, and although such risks may reasonably be taken when ancient and relatively unfossiliferous systems are concerned, it is unjustifiable to call in the "imperfection of the palæontological record" in the case of thick tested marine forms from the Lower Cretaceous. Secondly, *Conulus* shows specialization of the orad parts of the ambulacra, and complication of interradial ornament, that are definitely in advance of the normal conditions in the Holectypoida, and certainly far more elaborate than the corresponding features in *Pyrina* and *Echinonëus*. It would seem in the last degree improbable that such specialization should be evolved merely to sink back to, and even beyond, the level from which it rose. What, then, can be the relation between *Conulus* and the *Pyrina–Echinonëus* series?

At this stage it is profitable to consider the problem from a different point of view. *Echinonëus*, the only one of the three genera whose habits can be directly observed, lives (according to H. L. Clark) at or about low-tide mark in sheltered lagoons, clinging feebly to the under surfaces of rocks and picking up small pebbles and other fragments as a protective covering. It is eminently a shallow-water form. There is every reason to believe that the habits of *Pyrina* were essentially the same. I know of no record of the occurrence of the genus in this country at an horizon higher than the Chloritic Marl—the last well-defined littoral deposit in the English Cretaceous

system. In France, on the other hand, the genus ranges well into the Upper Chalk (Senonien), but occurs only in those districts where the deposits are full of detrital matter. In this respect it resembles most of the Holectypoida (excluding *Discoidea* and *Conulus*), and the deduction is surely sound that it was a genus confined to the littoral tracts of the sea. The extremely close correspondence in structure between *Pyrina* and *Echinonëus* thus seems associated with a similarity in habitat. *Conulus*, on the contrary, was certainly not restricted to shore-lines, or even to shallow water. The distribution of the recognized English species is particularly instructive. *C. rhotomagensis*, which occurs in the Selbornian, is superficially like a typical *Pyrina*, both in ambital outline and relative height. *C. castanea*, from the Lower Chalk and lower parts of the Middle Chalk, is still elongated, but shows almost *Globator* proportions in height. *C. subrotundus* is low and roundish in the zone of *R. cuvieri* (save for very large, almost globular, specimens, probably representing a distinct species, and here called *C.* sp.) but grows surprisingly tall in the zone of *Terebratulina*. *C. albogalerus* is relatively low (though markedly conical) in the lower zones of the Upper Chalk, but becomes exceedingly high, especially when large, towards the top of the zone of *M. coranguinum*. *C. rhotomagensis* is definitely a *Conulus*, but its "Pyriniform" characters suggest, not merely that it may have descended from *Pyrina*, but that it was living under conditions similar to those surrounding that genus. The two horizons at which species of *Conulus* attain their greatest height are those that seem to mark the deepest conditions that obtained during the dominance of the Chalk-sea over Britain; while the comparatively depressed forms from the lower parts of the Upper Chalk can be correlated with the Chalk-Rock uplift. The tendency for Echinoids, and other organisms, to become vertically elongate in deep water has often been remarked, and there seems every reason to consider *Conulus* as a clear illustration of that phenomenon. But for the present purpose it is important to recognize that *Conulus* departed morphologically from a Pyriniform character progressively as it adapted itself to a changing habitat. The reduction in size, and increase in numbers and irregularity of distribution, of its radioles invite comparison with the bristle-like nature of the radioles of most Irregular Echinoids that dwell in sand or ooze; while the elaboration of the tube-feet nearest to the peristome also points to an analogy with the phyllodes of the Echinolampidæ or the "pseudophyllodes" of Spatangoids. A logical deduction from these points is that, if *Conulus* had remained in the littoral zone, it would have kept the essential shape and characters of *Pyrina*, while its periproct, in obedience to the principle that seems always to influence that aperture, would have become first marginal (as, in fact, it did), and then infra-marginal. In brief, it would have developed into a form very much like *Echinonëus*. But by its desertion of the shore, and its preference for the oozy depths of the open sea, it underwent modifications that led it far away from the *Echinonëus* direction, and that produced more than a superficial likeness to the *Echinolampas* series.

In passing, it is of great interest to find that *Conulus*, the deep-water member of the group, is in so many respects the most "Holectypoid". The so-called "Cretaceous" fauna of the deeper parts of the Atlantic Ocean has often been regarded as owing its "antediluvian" character to the similarity of conditions in the ooze-belt of deposition, at whatever period it exists. This explanation, and the companion one that the reduction in the struggle for existence in thinly populated depths encourages the persistence of types whose extinction is overdue, seem reasonable enough, but they can hardly account for the revival of Holectypoid qualities in *Conulus*. Excepting *Discoidea*, *Conulus* is the only genus of the Holectypoida, as far as can be ascertained, that was not absolutely littoral in habitat. Its reassumption of Holectypoid features cannot, then, have been due to a return to "Holectypoid" surroundings; nor is there any reason to regard it as moribund. Perhaps, since the trend of normal Holectypoid evolution was one of improving adaptation to shore-line existence, *Conulus*, in abandoning that sphere of life, allowed the specially adaptive features to lapse and degenerate, while spurring on others for accommodation to the new and unfamiliar surroundings. In some such way it is possible to reconcile the combination in *Conulus* of some features more Holectypoid than those of its presumed ancestor, *Pyrina*, and of others far less Holectypoid than those of its sister *Echinonëus*.

The relationship between the three genera suggested in the preceding sentence appears to me to be the only one possible. It can hardly be said to be proved, but it accords with all known qualities of the forms concerned. The detailed analysis of some tubercle-patterns in certain species of *Conulus* that follows adds further points of support to the hypothesis. The taxonomic corollary which would follow its acceptance is clear. If *Conulus* is an Holectypoid (it would be unfortunate to exclude it from an order that was once called "les Galérites"), and if *Conulus* was derived through *Pyrina*, how much the more must *Pyrina* be an Holectypoid? *Echinonëus* must surely be placed in the same order with *Pyrina*. The only serious difficulty in the way of such a systematic grouping (assuming the phyletic foundation to be sound) comes in the uncertainty as to the ancestry of *Pyrina*. That genus may well have arisen from some such Pygasteridæ as *Macropygus* or *Anorthopygus*, but it is unlikely to have included any of the *Holectypus* series in its ancestry. The tubercle-pattern of *Anorthopygus* is distinctly Pyrinid, and its peristome is far from circular. But various Jurassic genera, among which forms called *Desorella*, *Nucleopygus*, or *Pyrina* are most noteworthy, might perhaps be claimed as forerunners of the Cretaceous group. If such a claim were substantiated, *Anorthopygus* would be too late to fall into the phyletic line. However, it would seem that the Jurassic forms that resemble *Pyrina* in shape and some other characters are always covered by tubercles whose order of inception is indeterminable. It would be very strange to find Irregular Echinoids, that had advanced so far beyond Holectypoid limits in this direction, reverting to the "Regular" quality of sparse, coarse, and serial tuberculation. In default of definite

evidence, the preponderance of probability favours an Holectypoid origin for *Pyrina*; so that, provisionally at least, *Pyrina* and *Echinonëus* must be included among the Holectypoida.

In the second paper of this series an account was given of the details of ornament developed in *Conulus*, particularly in *C. albogalerus*. The following notes deal with the main tubercles only, and treat of those morphogenetically, so that in a sense they supply particulars that were omitted in the previous account. But the purpose of this return to the subject of the ornament of *Conulus* is different. As Jackson has clearly shown, the "law of localized stages of development" is often very well illustrated by the tuberculation of the interambulacra of Echinoids. The plates towards the peristome, being ontogenetically young, show recapitulatory stages in ornament which (subject, of course, to modifications introduced after their formation) give valuable aid in tracing the ancestry of the form concerned. The plates of the mid-zone show the full "species-characters", while those near the apex, being morphogenetically young, provide a less convincing, but recognizable and partly prophetic, type of recapitulation. With a view to discovering the probable relationships of *Conulus* I have analysed interambulacral columns of three types (probably distinct species) from the English Chalk (see Figure, p. 445). A similar analysis of *Pyrina desmoulinsi* is given to show the similarity, and difference, between the genera in this matter. The species of *Conulus* are arranged in stratigraphical order—*C.* sp. (a large, subglobular form) is from the zone of *R. cuvieri* near Reigate, *C. subrotundus* (a tall variety) from the zone of *T. lata* near Wallingford, and *C. albogalerus* (a large, acutely conical form with a wide periproct—Gravesend type) from the sub-zone of *C. albogalerus*, about 20 feet below the zone of *Uintacrinus*, at Whitway, Hants. In all types supernumerary tubercles occur near the ambitus. These supernumeraries, which occur equally in *Discoidea cylindrica*, are clearly hypertrophied secondaries, and have no place in the fundamental scheme of tuberculation. They are interesting as showing one method whereby tuberculation may become multiplied and disordered, while the apicad pattern in *C.* sp. (and to a less degree in the two other species) show a second method producing a comparable result.

The interambulacral plates figured have been selected from the same columns and parts of columns as far as possible. For convenience in spacing on the page the columns of each species run horizontally. In the first vertical row the proximal orad plates are shown. Next comes a plate from the "mid-zone" of the adoral surface, and in the middle row a plate from the ambitus. The two right-hand columns represent plates from the "mid-zone" of the adapical surface, and the apicad plates. It has proved more satisfactory to select the plates in this way than to choose mid-zonal plates in the literal sense. The ambitus in all these forms has various specializations associated with it, and the disposition of the tubercles is usually very different on the two surfaces of the test. It is true that this tendency somewhat vitiates the application of the law of localized stages, but it cannot be avoided in forms with sharp ambital angles. In *Pyrina*, where

the ambitus is rounded, and comes about midway between the apex and the peristome, conditions are more favourable for a strict application of the law.

The diagram (p. 445) is practically self-explanatory, but a few points will bear verbal emphasis. In the orad plates, *Pyrina* shows three "Cidaroid" members, with one central tubercle each. These are followed by the fourth plate, which has one tubercle developed on each side of the median one, both being apicad in relation to the central tubercle. In *C.* sp. there are only two "Cidaroid" plates, and on the fourth plate the first orad additional tubercle appears on the adradial side. *C. subrotundus* is practically similar, but the third plate has assumed the full characters of the fourth in *Pyrina*. In *C. albogalerus* only one "Cidaroid" plate remains.

Turning to the second column of figures, which show the mid-adoral plates, *Pyrina* proves to have developed the regular chevron characteristic of *Anorthopygus*. The median tubercle is distinctly orad in position, and is in the same transverse line with the other orad tubercles of the plate. *C.* sp. is closely similar, but a "triplet" occurs on the adradial side, and the median tubercle is above the average level of the orad series, though still far from central. In *C. subrotundus* the median tubercle is nearly central, and a supernumerary occurs below it. This supernumerary is always present in ambital plates of both genera, and is strongly reminiscent of the similarly placed tubercle (usually sunken) on some adapical plates of *Holectypus depressus* and *Discoidea cylindrica*. *C. albogalerus* shows the "hour-glass" pattern so characteristic of the species; the relative simplicity of the tuberculation may be correlated with the small extent of the adoral surface in proportion to the length of the columns.

In the ambital plates *Pyrina* shows the true mid-zonal character. The median tubercle is nearly central, there are many supernumeraries, and a considerable proportion of triplets. *C.* sp. has a group of four, but otherwise the series of *Conulus* are very similar. It must be remembered that these three ambital plates are situated well below the true mid-zone of their columns.

Half-way up the adapical surface the tuberculation of *Pyrina* has recovered its simplicity, and, save for the smallness of the tubercles and the central position of the median one, is very like the corresponding tuberculation of the adoral surface. But *C.* sp. shows elaboration, passing beyond its ambital quality, while the two other species show little, if any, simplification.

In the apicad (newly formed) plates a strong likeness is seen in all four cases, but *Pyrina* introduces extra tubercle series most slowly, and *C. albogalerus* by far the most rapidly.

The fundamental agreement of all four species in the ontogenetically young plates (columns 1 and 2) is strongly suggestive of their phyletic relationship, while the introduction of additional tubercles is progressively accelerated. The morphogenetically young plates towards the apex may be regarded as showing prophetic characters (coupled inevitably with those due to immaturity), and from them it may therefore be deduced that *Pyrina* has reached it full specialization

in tuberculation, while *Conulus* is tending towards an increase in elaboration. The extremely rapid introduction of new tubercles in *C. albogalerus*, the latest species considered, suggests that any descendants of that form would have such complex and multiple tuberculation that the original "Holectypoid" quality of recognizable order in the pattern would disappear.

The results of this, and of the earlier, part of the paper may be tersely summarized as follows: *Pyrina* gave rise to *Conulus* early in the Cretaceous period. Later, in the Tertiary, *Pyrina* became modified into *Echinonëus*. The *Pyrina–Echinonëus* stock was almost static in evolution; but *Conulus*, with changed habitat, diverged rapidly along a new path which must have led away from the Holectypoida. Both *Pyrina* and *Echinonëus* must be classed with the Holectypoida.

EXPLANATION OF TEXT-FIGURE, p. 445.

All the figures in each horizontal line (i.e. representing a single species) are drawn to the same magnification; but the different species are variously magnified to aid comparison. The median tubercles on each plate are shaded. Apart from the dotted lines linking the elements of the chevrons, there is nothing diagrammatic in the figures (unless the omission of all smaller ornament be so regarded). Tubercles without shading or linking lines are either supernumeraries or members of chevron patterns whose associates are undeveloped.

III.—The Magnesian Limestone of Durham.

By David Woolacott, D.Sc., F.G.S.

Part I.

Conditions of Deposition—Former Presence of Sulphates—Formation of "Demagnesified" Rocks—Development of Concretionary and Segregated Structures,[1] etc.

In my paper on "The Stratigraphy and Tectonics of the Permian of Durham (northern area)" [2] I endeavoured to give a description of the stratigraphical and structural features of these rocks with as little discussion of the theoretical questions involved as possible. I regarded a thorough examination of the strata in the field as the only way in which to obtain a knowledge of the divisions of this system, and as essential for elucidating the structural, physical, and chemical changes that have taken place in the Magnesian Limestone. It was my intention to describe similarly the southern area, and afterwards to discuss theoretical and general questions relating to the Durham Permian. Although a great part of the southern district has been surveyed by me, I have decided to leave the description of that area and give in this paper a general summary of recent work on the Magnesian Limestone of Durham, with a discussion of the theoretical views that may be advanced to explain the observed facts,

[1] In Part I of this paper a general acquaintance with the divisions of the Magnesian Limestone and with certain structural features of this rock is presupposed; readers not having such preliminary knowledge will find these subjects summarized and discussed in Part II.

[2] Proc. Univ. Durham Phil. Soc., vol. iv, pt. v, 1911–12.

and a statement of our present knowledge of these rocks. I am able to do this more readily as part of the southern Permian has been described and much careful work done on the lithology and composition of these rocks by Dr. Trechmann [1] (to whose work I must record my indebtedness in the preparation of parts of this paper); and two borings that have lately been put down have given an opportunity for the examination of one of the least known facies of the Middle Limestones.[2]

The uneven floor of the broad syncline of the Northumberland and Durham Coalfield was covered by a series of dunes on the edge of the Permian sea, which was advancing from the east. These were gradually planed down by the incoming waters, the Yellow Sands being formed. This deposit usually consists of large rounded grains set in a finer angular-grained matrix. The basin in which they were laid down extended far to the east, but on the west it was bounded by the Pennine area, and on the south by an anticline of Lower Carboniferous rocks which then lay across the south of Durham. Fragments of the latter rocks with derived encrinite stems occur in the Yellow Sands in the south of the county, proving that this ridge was being denuded when these sands were being deposited. On these reassorted sands a finely laminated calcareous and dolomitic mud—the Marl Slate—was laid down under tranquil conditions in fairly deep off-shore waters. Eventually the southern ridge was covered by deposits of the limestone facies and the sea thus overspread the country to the south, and deposition went on continuously from Durham to Central England.

The Magnesian Limestone, which reached a thickness of about 1,000 feet, was deposited in an inland sea which was gradually drying up, so that conditions were brought about which led to the gradual precipitation of the dissolved salts. The strata originally varied from nearly pure calcareous rocks to pure dolomites, along with which were beds, veins, and intercalations of gypsum and anhydrite, and in the later formed rocks of marls, marly sandstones, and rock salt. The main mass of the Magnesian Limestone thus consists of (*a*) thick and thin beds—often lenticular—of nearly pure calcium carbonate, (*b*) beds of nearly pure dolomite, (*c*) beds composed of mixtures in varying proportions of dolomite and calcium carbonate—these are the dolomitic limestones consisting of dolomite and interstitial calcite, and (*d*) (where they have not been removed) beds, veins, etc., of calcium sulphate.

Irregularly distributed throughout the limestone are various substances, some of which are due to original deposition, while others are of secondary origin. Among such substances are alumina, chert, iron oxides, manganese dioxide, grains of quartz (both of detrital and non-detrital origin), and, in a lesser degree, of mica, tourmaline, zircon, etc. In geodes and cavities crystals of calcite are common, while dolomite is only occasionally found. Ankerite, fluorite, galena, iron pyrites, malachite, heavy spar, and limonite (pseudomorphs

[1] Q.J.G.S., vol. lxix, pp. 184–218, 1913, and vol. lxx, pp. 232–65, 1914.

[2] "Borings at Cotefield Close and Sheraton": GEOL. MAG., March, 1919, pp. 163–70.

after chalybite) also occur. Parts of the limestone contain a small amount of carbonaceous matter of organic origin, and some of the limestones are fetid.

The limestones vary in colour, texture, macroscopic and microscopic structure considerably. These variations are partly due to the differences in composition and partly to the different methods of formation of the beds, but also largely to the nature of the physical, chemical, and structural changes that have taken place in them. In colour they range through dark and light brown, yellow, grey to pure white rocks, and the numerous varieties of their texture include fine, soft and powdery, hard and compact, close-textured, porous, coarsely cellular, concretionary, crystalline, segregated, brecciated, pseudo-brecciated, etc. Thick beds of granular dolomite occur, and in the Middle and Upper divisions strata of dolomitic oolite reach a considerable thickness. Parts of the limestone consist of the remains of organisms with a dolomitic or calcareous matrix. In microscopic texture they vary from rocks showing little or no structure to beds built up of allotriomorphic grains and idiomorphic rhombs of dolomite and crystalline grains of calcite. In some parts of the limestone crystallization has gone on to such an extent (quite apart from the highly altered concretionary, segregated, and other limestones where the change is evident in the field) as to entirely alter the internal structure. Original oolitic rocks have been altered so as to leave but little trace of their structure, and from parts of the Bryozoa Reef the fossils have been entirely obliterated.

Parts of this limestone are of organic origin, this being notably the case in the shell bank of the Bryozoa Reef, which consists of remains of invertebrate life that flourished under the protection of the Bryozoa, together with an infilling of calcareous or dolomitic sediment. The pure calcareous inorganically formed rocks, and some of the dolomitic limestones are the result of sedimentation. The oolites of the magnesian limestones, which attain a considerable thickness (100 feet) in parts of the Middle and Upper limestones, are specially interesting. The concentrically arranged material of the ooliths is dolomite with centres of calcite, gypsum, or fluorite.[1] Gypsiferous oolites have been proved in the borings in South Durham, and the hollow oolites of Roker and Hartlepool had originally gypsiferous centres. The fluorite is probably secondary, being deposited after the solution of the gypsum. These dolomitic and gypsiferous dolomitic oolites were produced by the deposition of material round crystalline grains or nuclei either as they fell through the water or lay on the bottom of the sea.[2] They show no trace of current bedding,[3] were probably laid down in fairly deep water, and do not appear to have been produced through movement by current action, nor were they formed by organic agency.

The dolomitic limestones when the sulphates have been removed

[1] Trechmann, Q.J.G.S., vol. lxx, p. 250.

[2] "On Oolites and Spherulites": H. Bucher, *Journ. of Geol.*, vol. xxvi, No. 7, Oct.–Nov., 1918.

[3] Current bedding is traceable locally in the Roker oolite, and I have noticed it slightly developed in an altered oolite in Silkworth Quarry.

are really mixtures of dolomite and calcium carbonate in varying proportions. Analysis of this rock have been published giving a higher percentage of magnesian carbonate than the dolomitic ratio, viz. 45·7.[1] I always thought these wrong and misleading, and the work of Dr. Trechmann on the composition of these rocks has definitely proved them to be so.[2] The best way, therefore, to state their analyses for geological work is to give, as Trechmann has done, the percentage of dolomite and calcite, together with the smaller amounts of other substances present. The relative proportion of dolomite and calcite in the rock along with the original presence, of calcium sulphate has probably had, as I shall endeavour to show most important influences on the nature of the changes—segregational, concretionary, etc.—that have taken place on such a marked scale in these rocks. The presence of impurities has also had an effect on the structural changes, e.g. the presence of argillaceous and siliceous impurities appears to have deterred the formation of the concretionary structures, and Dr. Trechmann has suggested that the dolomitization of certain parts of the Reef has been arrested by the occurrence of manganese dioxide.

The original presence of calcium sulphate in the Permian rocks is not now a matter of conjecture. In 1875 Dr. T. Sterry Hunt [3] and in 1881 Wilson [4] suggested that calcium sulphate was a subsidiary product of the deposition of dolomite and it has been known for many years that gypsum and anhydrite were associated with the Permian rocks. These substances are found in Permian strata in the Vale of Eden,[5] near St. Bees Head, and in the Zechstein of Germany, and have been proved to occur in the Magnesian Limestone of South Durham, Yorkshire and North Lincolnshire.[6]

The precipitation of calcium sulphate would appear to have been a product of the deposition of dolomite and dolomitic limestones,

[1] Analysis by Browell and Kirkby, Nat. Hist. Trans., vol. i, pt. xi, p. 204, 1866.

[2] Q.J.G.S., vol. lxx, p. 232, 1914.

[3] *Chemical and Geological Essays*, 1875.

[4] "The Permian Formation of N.E. England": Mid. Nat., vol. v, p. 202, 1881.

[5] Regarded as Trias by some geologists.

[6] Anhydrite and gypsum have been proved by borings in the Permian at Seaton Carew (Wilson, Q.J.G.S., vol. xliv, p. 781, 1888); Whitehaven, near Norton (Tate, Q.J.G.S., vol. xlviii, p. 488, 1892); Hartlepool (Trechmann, Q.J.G.S., vol. lxix, p. 184, 1913); Leeming Lane; near Stockwith, North Lincolnshire (G. Dunston, Fed. Inst. Min. Eng., vol. xii, p. 578, 1896–7); in borings in South Yorkshire. Concealed coalfield of Yorkshire and Nottingham (Walcot Gibson, Mem. Geol. Surv., 1913); at Market Weighton (Walcot Gibson, Summary of Progress, Geol. Surv., p. 43, 1917). Trechmann gives the following analysis of the Seaton Carew boring (Q.J.G.S., vol. lxix, p. 193, 1913):—

	Feet.
Sulphate-free limestone	480
Limestone impregnated with gypsum and anhydrite .	358
Pure anhydrite and gypsum	35
Total thickness of magnesian limestone .	878

The mass of anhydrite and gypsum at Hartlepool was 267 ft. 2 in. It was overlaid by glacial deposits, so it may have been originally much thicker.

calcium sulphate forming and being deposited when the solution became saturated. In areas where the magnesian limestone is still covered by a mantle of later rocks the sulphates remain intact, but from this limestone in the greater part of Durham they have been removed. Trechmann's analyses show that many of the limestones in Durham (in areas where the beds and intercalations of gypsum or anhydrite have been removed) contain a small percentage of sulphates, and lately crystals of gypsum have been found in geodes in the lower limestone at Raisby Hill Quarry in South Durham. The evidences of the former existence of sulphates is to be found in the letting down of beds,[1] in some of the extensive disturbance and brecciation of the strata, in the hollow oolites of Roker and Hartlepool, and in cavities left by crystals and crystalline aggregates. Indirectly their solution had most important influences, not only did it render the rock highly cavernous, cellular, and porous, but at the time of its removal the strata would be saturated with solutions of calcium sulphate, which appear to have had marked effects on certain parts. As I shall endeavour to show, the stewing of the magnesian limestone in warm solutions of calcium sulphate, sometimes under high pressure, has been the factor that has altered large parts of it into a more calcareous rock.

The conditions in which the magnesian limestone was deposited were those of an inland sea containing various salts in solution. According to chemical theory these salts would be existing as ions, and so the solution would contain Ca'', Mg'', K', Na', H_2CO_3'', SO''_4, Cl'. When in equilibrium various compounds would be existing, such as $CaCO_3$, $CaCl_2$, $MgCO_3$, $MgSO_4$, $NaCl$, Na_2SO_4, etc., together with disassociated ions. Owing to varying conditions of temperature, pressure, and concentration, there would be a tendency for the formation of the least soluble and most soluble salts, thus calcium carbonate and magnesium sulphate would be formed. The magnesium sulphate afterwards acted on part of the calcium carbonate to form either free magnesium carbonate or the double salt, dolomite. If free magnesium carbonate were deposited, then the two separately precipitated carbonates must at a later stage have combined to form dolomite. Calcium sulphate would be formed as a subsidiary product, and deposited according to the concentration and temperature. Gypsum or anhydrite were deposited with the variation of conditions in thick beds, in veins, in irregular pockets,[2] or were irregularly intercalated throughout the limestone.[3]

[1] A considerable thickness of limestone (some 200 feet) appears to be absent on the west side of Cleadon Hills, and it may be that a thick bed of sulphate has been removed here. The extensive slipping down of beds and consequent brecciation along the eastern side of the Reef, which can be seen at several places along the Durham coast, is most probably due to this cause. Trechmann has noted several vertically slickensided surfaces (Q.J.G.S., vol. lxix, p. 201).

[2] Geodes containing gypsum with dolomitic rhombs disseminated through them have been observed by Trechmann.

[3] Anhydrite was deposited in periods of drought and higher temperature. See discussion of this subject by B. Smith in "The Chellaston Gypsum-breccia and its relation to the Gypsum-anhydrite deposits of Britain": Q.J.G.S., vol. lxxiv, p. 195.

Similar conditions of deposition held good through a protracted period, during which some 600 to 700 feet of rock were formed. The Permian Sea became shallower, marls, marly false-bedded sandstones and sodium chloride were deposited, and finally all the calcium and magnesium carbonates having been laid down, the more soluble salts were precipitated. These are represented by the Stassfurt deposits, which probably extend far to the west of their present proved position, or by deposits of similar nature now denuded.

The field evidence is in favour of some of the dolomite being originally deposited as a precipitate. Thick beds of powdery dolomite (some of which are called "marl")[1] occur in a very fine state of subdivision which would appear to have come down as dolomite, otherwise it would be expected that in the slow process of formation by the association of the carbonates after deposition, crystallization would have taken place in these rocks, and rhombs of dolomite have been formed. The dolomitic oolites also appear to me,[2] as Trechmann has already asserted, to support the view that the dolomite was originally deposited round the centre of the oolith. On the other hand, some of the more coarsely granular dolomitic rocks composed of coarse dolomite rhombs[3] may have been formed by the slow crystallization of the dolomite from the association of the free carbonates after precipitation. It may thus be that in the Durham Permian dolomite has sometimes been precipitated, while at other times the two free carbonates have been laid down to subsequently combine into that mineral.

It has already been stated that the beds of magnesian limestone differed considerably in composition at the time of their deposition, but since then important changes have taken place on various horizons. Dolomitization of certain parts has been brought about either pene-contemporaneously with the deposition of the strata or long after they were formed,[4] portions have been silicified,[5] other

[1] Trechmann gives an analysis of the Great Marl bed of Fulwell Quarries—

Dolomite	78·42
Calcite	13·04
Insoluble residue	5·02
Calcium sulphate	trace
Iron or manganese	2·41

[2] Trechmann gives an analysis of dolomitic oolite from Haswell—

Dolomite	96·49
Calcite	3·80
Anhydrite gypsum or sulphur trioxide	0·07
Iron or manganese	0·57
Insoluble residues	0·02

[3] The coarse granular dolomite occurring in the Cotefield Close boring gives (analysis by A. D. N. Bain, B.Sc.)—

Dolomite	62·38
Calcite	30·10
Ferric oxide	3·88
Insoluble residue	3·46

[4] [For note see next page.]

[5] Silicified limestones occur at the south end of Marsden Bay, Hendon, etc., and Trechmann has noticed silicified oolitic limestones.

parts have been decalcified by manganese or other solutions,[1] but the most interesting alteration is, as I stated in my paper some years ago, that large areas and considerable thicknesses of the magnesian limestone of Durham are more calcareous than they were originally. This latter change has been brought about by solution and also by the mechanical removal of dolomite. I first referred to it in my paper on the Permian of North Durham as "dedolomitization", a term the use of which in this connection was objected to by Garwood and Evans, as it has been used by Teall and others in another sense. If, however, the alteration of a limestone into dolomite is "dolomitization", then surely the alteration of the latter rock into a calcareous one is the simplest case of dedolomitization. As long as it is recognized that large masses of the magnesian limestone are more calcareous than they were originally, I have no desire to use any term, but as some word would be useful (if dedolomitization is inadmissible) I would suggest "demagnesification" for the processes—solution and mechanical—by which parts of this rock have been rendered more calcareous. As I shall show, "demagnesified" beds, both due to solution and mechanical processes, are of wide occurrence and thickness. The mechanical removal of dolomite by running water from the magnesian limestone has been admitted by Professor Garwood, Dr. Evans, and Dr. Trechmann. It is obvious as a result of the setting free of dolomitic powder in the rocks in which the concretionary and segregated processes have taken place. Objection has, however, been taken to my views regarding the solution of magnesian carbonate out of dolomite. Dr. Evans has asserted that "there is in the case of the Magnesian Limestone absolutely no evidence that magnesia has anywhere been abstracted

[4] Parts of the Bryozoa Reef have been dolomitized, e.g. Trechmann records the shell substance of a *Productus* as containing 95·88 per cent of dolomite, and of an *Arca* 98·68. Much of the sediment which fell on the reef was calcareous, and there is little doubt that the highly dolomitic nature of parts of the reef is due to subsequent dolomitization. This may have gone on pene-contemporaneously with deposition by the magnesium waters of the sea, lime being removed and replaced by magnesia, in the same way that the coral reefs of the present day have been proved to undergo a process of dolomitization (Judd, "Atoll of Funafuti," Royal Soc. London, 1904). Certain observations on the decalcified rocks in the reef, however, lead me to think that the dolomitization of parts of it may have taken place long after deposition. It is possible, if the solution changes which are discussed in this paper have taken place, that the magnesium may have been transferred from one part of the limestone to another. This appears to be so in the case of parts of the reef, and in some of the dolomitized highly calcareous rocks known as "bluestones" both in the upper and lower limestones. I have lately examined breccias occurring in the lower calcareous limestones of Raisby Hill Quarry which have been formed by the alteration of these rocks by magnesium and other solutions (see Breccias, Part II of this paper).

[1] Portions of the reef have been partially decalcified by manganese solutions, Tunstall Hill, Fox Cover Quarry, Beacon Hill. Trechmann gives an analysis of a decalcified rock from Tunstall Hill—

Dolomite . . .	3·94
Calcite	89·03
Insoluble residue . .	·19
Manganese dioxide .	7·00

from dolomite".[1] The evidence can be clearly studied in the field, and a discussion of it is given in the following pages. Dr. Trechmann admits the solution of dolomite, and while saying that he finds no evidence for the leaching out of magnesian carbonate from dolomite, yet adds "the question as to whether in the presence of saturated solutions of calcium sulphate the dolomite was as stable as it is under present conditions remains a problematic one."[2] I think that the evidence in the field is clear that under certain conditions the magnesian carbonate in solution has been carried away as a soluble salt from the dolomitic limestones is clear. The important point, however, is not the manner in which these changes were produced, but the the fact that large portions of these rocks—both cellular and non-cellular—are more calcareous than they were originally, and that the chief cellular types of the limestone were not produced by dolomitization.

There are five rock types occurring in these limestones which have a less content of magnesian carbonate than they had. They are (1) dolomitic rocks and breccias altered into calcareous rocks chiefly in regions of pressure at the time of thrusting without the production of a cellular structure, (2) the concretionary limestone, (3) the segregated limestone, (4) the "fractured cellular" rocks, and (5) the "negative breccias". The last four usually result in the production of a highly cellular calcareous rock. As each of these rocks present certain characteristic features, it may be well to consider them separately.

(1) In the area affected by the thrusting and locally at other places, parts of these dolomitic limestones have been rendered more calcareous without the production of either a cellular, concretionary, or segregated structure. These changes are mainly found in the area affected by the thrust-movements and would appear to be due to solubility-conditions set up in the rock in the regions of pressure and heat developed at that time. These alterations are best seen in the dolomitic rocks above and beneath the thrust plane at Hendon, Sunderland, and in the mass of highly slickensided calcareous breccia (originally a dolomitic limestone) forming Jean Jiveson's Rock south of this thrust plane and probably connected with it, and in other areas. The dolomitic Flexible Limestone at Hendon becomes a hard, non-cellular, calcareous rock, and then a calcareous brecciated mass on the underside of the thrust plane, the change taking place within 100 feet and being easily traceable.[3]

The breccia of Jean Jiveson's rock occurs in another area of pressure relief, and it is here possible to trace the gradual change

[1] Q.J.G.S., vol. lxx, p. 264.

[2] Ibid., p. 253.

[3] This section is noticed in my paper on "The Permian of N. Durham", op. jam. cit., p. 267, 1912, and is drawn and described in fig. 10, where I refer to the change as having been brought about by the leaching out of the magnesium carbonate from the dolomite. Dr. Trechmann also fully describes it (Q.J.G.S., vol. lxx, p. 252, 1914), and explains the alteration as being due to the solution of dolomite. The amount of interstitial calcite in the Flexible Limestone is usually very small, so that solution of dolomite demands the

from a dolomitic rock to a highly compressed, slickensided, compact, calcareous breccia.[1] The change here has been similar to that in the case of the Flexible Limestone. In Fox Cover Quarry, Seaham Harbour, in rocks apparently not affected by pressure, a large mass of the Reef has been changed by solution from a dolomite into a nearly pure limestone. The dolomite can be seen to pass gradually into the calcareous rock, and when the alteration is complete the fossils are entirely obliterated. Other altered rocks and breccias of a similar nature occur. These changes have not been brought about by the mechanical removal of dolomite from the magnesian limestone, but by solution. There would appear to me to be two methods of explaining this: (1) the dolomite has been dissolved and metasomatically replaced by calcite, or (2) the magnesium carbonate has been carried away as a soluble salt out of the dolomite, calcium carbonate metasomatically replacing it.

(1) That direct solution of dolomite may have gone on in a small degree is undoubted, but I do not think that it has taken place on any large scale in the magnesian limestone, and am of the opinion that the carrying away of the magnesium as a soluble salt is in the main the explanation of these altered rocks. If these changes were brought about by direct solution of dolomite, more of this mineral would occur in geodes, as such a slightly soluble substance (in comparison with calcite) would be redeposited in other parts of the rock if the pressure conditions were the factor determining its solution. Another significant fact is that most of the altered limestones originally contained a very small percentage of interstitial calcite. It is also difficult to conceive of a solution dissolving dolomite under these conditions and at the same time containing calcite to replace it—if it was not immediately replaced owing to the small percentage of interstitial calcite the rock would have been broken up and the strata disturbed. Alteration of the Flexible Limestone occurs, however, without any disturbance, and the brecciation of other altered rocks was brought about by thrusting and is not directly due to solution changes. In the solution of magnesium carbonate from dolomite in the presence of calcium sulphate, calcium carbonate is produced in the reaction, and there is besides the interstitial calcite and calcite of the dolomite.

solution of almost the entire rock and its replacement by calcite, e.g. Flexible Limestone, Marsden, interstitial calcite 0·71. The analyses given by Dr. Trechmann of this bed above the thrust plane at Hendon are—

	Flexible Limestone.	Hard Calcareous Rock (altered Flexible).
$MgCO_3$ . .	43·78	10·92
$CaCO_3$ . . .	55·01	88·56
Fe_2O_3 . . .	0·61	0·19
Insoluble residue .	0·88	10·92
Dolomite . .	95·91	23·93
Calcite . . .	2·88	75·55

[1] This section is drawn and described in my paper on "The Permian of N. Durham", op. jam cit., fig. 10.

(2) The second explanation is that the magnesium has been carried away as a soluble salt out of the dolomite, calcium metasomatically replacing it. It appears to me, that under certain conditions, the reaction represented by the following reaction took place: $CaCO_3\,MgCO_3 + CaSO_4 = 2CaCO_3 + MgSO_4$.

If dolomite was precipitated, as suggested in a former part of this paper, by the formation of calcium carbonate and magnesium sulphate in solution and their reaction on one another, then the process of formation of dolomite has been reversed at the time of solution of the magnesium carbonate. On this hypothesis the reaction represented by this equation, $2CaCO_3 + MgSO_4 \rightleftharpoons CaMg(CO_3)_2 + CaSO_4$, is considered to be a reversible one. The reversibility will depend on the temperature, pressure, and concentration of the solution. It is impossible to be dogmatic on such changes, as little is known regarding the exact way in which dolomite is produced in nature. The reaction for the formation of dolomite by the action of magnesium sulphate on calcium carbonate has been obtained at fairly high temperatures (120°), but F. W. Pfaff has shown that when a current of carbon dioxide is passed for a long time through a warm solution of the sulphates and chlorides of magnesium and calcium, and slowly evaporated at a temperature of 20° to 25°, a residue is produced which contains the double carbonate, i.e. under conditions approximately parallel to those which occur in the concentration of sea-water, dolomite may be formed (*Centralblatt. Min. Geol. u. Pal.*, p. 659, 1903).

The same authority says that it is a well-known fact that dolomite with gypsum solution is changed to magnesium sulphate and calcium carbonate at ordinary temperatures and pressures. He describes a simple experiment in which the reaction can be proved. Powdered gypsum and dolomite are mixed with one another, placed in a funnel, the stem of which is stuffed with cotton wool, and water is poured on the mixture and allowed to trickle through. In the clear filtrate magnesium can be proved in appreciable quantities (F. W. Pfaff, "Ueber Dolomit und seine Entstehung": Neues Jahrbuch für Mineralogie, Geologie, und Paläontologie, p. 563, May, 1907). The experiment has been verified by Mr. A. D. N. Bain, B.Sc., who finds that the reaction can be proved to take place quite easily if the temperature of the solution is raised. Since arriving at the idea of the reversibility of this equation I have noticed the following statement:—

"A. von Morlot by heating powdered calcite with magnesium sulphate to 200° in a sealed tube, transformed the carbonate into a mixture of dolomite and gypsum. This reaction has been suggested by Haidinger in order to account for the frequent association of the two last-named species. The process, however, is reversible, and solutions of gypsum will transform dolomite into calcium carbonate and magnesium sulphate. Efflorescences of the latter salt are not uncommon in gypsum quarries, and H. C. Sorby has observed them in Permian limestones. Because of this reaction, according to Sorby, the upper beds of magnesian limestone are often more calcareous than the lower. Their content in magnesia has been diminished in this way" (*Data of Geo. Chemistry*, p. 535).

Sorby suggests that probably the alteration of some magnesian limestones was affected by the percolation of magnesium salts, and adds: "a process the very reverse of that just described is now taking place by the action of dissolved gypsum, by which sulphate of magnesia, frequently effloresceing on the surface of the rock, and carbonate of lime are produced" (Reports Brit. Assoc. Sci., p. 77, 1856). This geologist had evidently arrived at the same conclusion as I have from direct observation in South Yorkshire regarding the action of gypsum on dolomite.

(If it is objected that the calcium sulphate solutions were all removed from the rock at the time of thrusting, it must be remembered that in the natural waters contained in the rocks there would be other dissolved substances, e.g. common salt, etc., which may have had an influence in bringing about the solution of the magnesium, and that under the high pressures existing at that time —which I have endeavoured to prove reached in the Marsden area a pressure of some 300 tons per square foot—the solution effects of carbonic acid would be greatly increased. I, however, see no reason for doubting that the main factor for the solution of magnesium carbonate from dolomite was the presence of calcium sulphate solution in the rock.)

The dissolved magnesium salt may have dolomitized other parts of the limestone in regions of less pressure and lower temperature, or where the concentration was different, or have been carried entirely away in the same manner as the calcium sulphate.

It should be noticed that in this type of demagnesified rock, where the alteration is complete owing to the non-production of a cellular texture, no mechanical removal of dolomite is taking or has taken place.

2. The concretionary limestones were originally dolomitic limestones, and there can be little doubt that these rocks were impregnated with sulphates and that the solution of these brought the bed into a condition which gave the concretionary forces full play; and further it would seem highly probable that the complicated structures occurring in these rocks were mainly produced when the beds were saturated in solutions of calcium sulphate containing colloidal organic matter.[1] It is the presence of this latter material that causes the spheroidal condition. Colloids readily permit the diffusion of crystalline salts through them. The effect of colloids on calcium carbonate in producing concretionary growths has been proved by Rainey, Harting, Ord, and Stocks.[2] I have before referred to the presence of colloidal matter as a factor in causing the concretionary limestone,[3] and Trechmann has also suggested that the spherical concretions are due to the presence of organic matter when they were forming.[4] The Bryozoa Reef probably formed the reservoir from which the organic matter came. I have divided the concretions

[1] The concretionary limestones often contain organic matter and are sometimes strongly fetid.

[2] Stocks, Q.J.G.S., vol. lviii, pp. 46–58, 1902.

[3] Univ. Durham Phil. Soc. Proc., vol. iv, pt. v, p. 271, 1911–12.

[4] Q.J.G.S., vol. lxix, p. 198, 1913.

into two types, the spherical and the cellular, which are associated together in the same beds, and similar conditions would appear to have brought them about. The large irregular spherical concretions, the cannon-ball, botryoidal, and stellate types, do not occur on any definite horizons, but are found irregularly through the Concretionary Limestone. It seems probable that the more spherical calcareous growths were produced in parts of the solution where the colloidal organic matter was more concentrated. While the calcite which forms the concretions is in the main part the interstitial calcite, it is possible that if the rocks were saturated in sulphate solutions part of the dolomite has been decomposed, the magnesium being carried away as a sulphate and the calcite crystallizing along with the interstitial calcite. It is difficult to understand how the large, irregular, spherical (often more than 2 ft. across), non-cellular concretions and the smaller compact cannon-balls can have been formed without such solution having taken place. The matrix and loose dolomitic material surrounding the spherical concretions and found in the cellular concretionary rocks is always fine and powdery, and the question arises was the dolomite in these concretionary rocks always powdery and never granular or oolitic.[1] The calcium carbonate in certain of the concretions does not appear to have come together out of the rock, but the change seems to have been brought about by gradual alteration outwards from the centre. Specimens can be obtained varying from soft, yellow, unaltered highly dolomitic beds to rocks in which clearly defined spherules of calcite have been formed (the dolomitic limestones around these remaining unaffected), such rocks finally by coalescing of the spherules becoming grey, concretionary, calcareous, and only slightly cellular. It is very questionable to me whether this particular change is only due to the crystallization of the interstitial calcite and does not imply solution of the magnesium carbonate. As specimens showing such variations can readily be obtained, observers are inclined to think that changes of this character are taking place at the present time, but this is exceedingly doubtful; indeed, it is much more probable that these complicated rock-structures are now more or less stable, and that in the main the concretions were produced at some time in the past under the conditions just defined. As Sedgwick pointed out in 1835, the concretions were formed after deposition, and I have shown that they must have been mainly produced before the folding and dislocation of the strata took place. In one case a brecciated mass, which occurs on the coast just north of Byers Quarry, Marsden, has had a crystalline concretionary structure developed in it subsequent to brecciation, but this is quite exceptional. Whether any solution of the magnesium content of the dolomite has gone on in these rocks by the action of solutions of calcium sulphate on them or not, it should be noticed that the loose dolomitic powder, which is at present being removed mechanically from them under existing conditions of denudation (and in Durham similar conditions over more extensive areas would hold good before the country was

[1] Trechmann lays emphasis on the very fine state of the powdery material in both the concretionary and segregated rocks (Q.J.G.S., vol. lxx, pp. 252, 256).

covered by the boulder-clay), is not in any way connected with the cause of the formation of the concretions, but is set free as the result of the alteration of these beds by the concretionary processes.

3. The segregated limestone are also due to the crystallisation of calcium carbonate from dolomitic limestones, but here the growth of the calcium carbonate is irregular, assuming no definite forms.[1] They are specially characteristic of the Middle Limestone on both sides of the Reef, reach a thickness of at least 90 feet, and have a considerable extension in these beds. They were originally dolomitic limestones of intermediate composition and probably were always originally gypsiferous. During the metamorphism the entire structure of the rocks has been altered, the fossils when present obliterated, and the composition, texture, and colour changed. This alteration of these beds had also largely taken place before the thrusting (although solution and segregation of calcium carbonate can also be proved to have gone on both during and after the deformation of the strata). Dr. Trechmann has said that loosening of dolomitic grains would be brought about merely by the leaching out of the gypsum, and this would be so, but it appears to me probable that in these rocks the segregation of the calcareous portion of the rock may have taken place in sulphate solutions, and much solution of the magnesium carbonate of the dolomite may have gone on. The dolomitic matter found in the cavities is always in a fine state of subdivision as it is in the concretionary limestone, while in the Middle division of the limestones thick unaltered beds of coarse granular dolomitic grains occur, and of dolomitic oolite, and the question arises what was the original nature of the dolomite in parts of these highly altered beds. It is again also noticeable that the unsegregated dolomitic limestones from which the altered rocks were formed do not contain a high percentage of interstitial calcite.[2] Another point of interest is whether the non-concretionary nature of the calcite in these rocks is owing to the solution not having contained collodial organic matter. In this connexion it is significant that the concretionary limestones lie above the segregated. In the latter rocks—whatever may be the way in which they were altered—the calcium carbonate has segregated out, and as a result loose powdery dolomitic material has been set free, which has been, and

[1] Trechmann gives the following analyses from the coast near Horden—

	Dolomite—soft, yellow, well bedded.	Calcareous Segregation.
Dolomite . . .	96·08	31·94
Calcite . . .	0·58	65·50
Insoluble residue .	3·14	3·14
Iron or manganese	0·61	·61

[2] An analysis of a hand specimen by the late R. C. Burton, B.Sc., of fossiliferous dolomite passing into a segregated limestone from which the fossils were obliterated gave—

	Dolomitic Limestone.	Segregated Limestone.
$CaCO_3$ . .	50·39	91·92
$MgCO_3$ . .	40·93	8·01

In both the unaltered rocks the interstitial calcite is small, in the first case exceedingly so.

is being, mechanically removed. The rock as a whole is thus finally losing the greater percentage of its magnesium-content. These segregated rocks are often broken up without much displacement, being generally compactly recemented, thus forming one class of pseudo-breccias.

In the case of both the concretionary and segregated rocks the solutions must have been saturated so that solution and precipitation were going on at the same time, otherwise the stability of the rocks would have been affected and the strata broken up. The water which filled every cavity and pore would also help to prevent the collapse of the rocks at the time the structures were forming. The pseudo-brecciation, brecciation, and disturbances of the strata can generally be proved to have taken place after the structures were developed in them.

4. The other type of cellular limestone from which dolomite has been removed is the rock I have named the "Fractured-cellular". Here again alteration of dolomitic limestone into a calcareous rock has taken place along fractures and lines (apparently necessitating solution and segregation changes similar in nature to those already discussed) and the loose dolomitic rock is then mechanically removed. This type is well exposed along the coast to the south of Seaham Harbour.

5. Between Frenchman's Bay and Marsden dolomitic rocks have been brecciated along a thrust plane, and subsequently bound together by a calcareous cement. This material may have been derived by solution from the dolomitic powder produced at the time of thrusting, when there would be both high temperature and increased pressure, or may have been segregated out of the fragments, or may have been brought in from the rocks above. At the present day the dolomitic limestone of the breccia is loose and powdery, and is being removed mechanically. The original dolomitic breccia thus becomes a highly, and very coarsely cellular, calcareous rock, i.e. a "negative breccia".

The evidence for these alterations in the magnesian limestone can only be studied in the field, and there is no doubt that the more these rocks are observed, the more striking do the extensive changes become. The theories advanced in this paper are not put forward in any dogmatic manner, but merely as an attempt to explain them.

(*To be continued.*)

ADDENDUM.

1. Where statements are made regarding the composition of rocks and analyses were not available they have always been analysed, generally by post-graduate students of Armstrong College.

2. In connexion with solution changes in the magnesium limestone, it is perhaps worthy of note that Sunderland Water contains on the average—

	per 100,000.	Grains per gallon.
CaO . .	10·99	7·69
MgO . .	6·38	4·47
SO_3 . .	3·83	2·68
CO_2 . .	12·42	8·69

As a very large and busy manufacturing district obtains all its water from this formation, large quantities of both calcium and magnesium must yearly be dissolved out of the magnesian limestone.

IV.—The Distribution of '*Terebella*' *cancellata*.

By Dr. F. A. Bather, F.R.S.

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'*Terebella*' *cancellata* was the name given to some supposed worm-tubes from the Cenomanian of the East and South-east of England, in the Geological Magazine for December, 1911 (p. 553, pl. xxiv, figs. 3–5). The chief feature of the species is an obscure cancellate ornament formed by transverse and longitudinal folds.

At that time these fossils were recorded from the *Holaster subglobosus* and *Actinocamax plenus* zones of the Cenomanian. The only exception was the British Museum specimen A 1638 from the Upper Greensand (Albian) of Betchworth, Surrey. Some other horizons can now be added.

Aptian: Specimen A 1702, collected from the Lower Greensand of East Shalford, Surrey, by Caleb Evans.

Turonian: a specimen submitted in June, 1917, by Mr. H. C. Brentnall, of Marlborough College, and obtained "just N. of the main road over Overton Hill and S. of the short stretch of Roman Road, just W. of the 4th milestone. On the 6 in. map, Wiltshire, Sheet XXVIII S.W., the actual shallow excavation is shown under the word Tumuli". This is probably the "small pit" in the Chalk Rock, zone of *Holaster planus*, mentioned on p. 197, par. 5, of Mem. Geol. Surv., Cretaceous Rocks of Britain, Vol. III.

Lower Eocene, Thanetian: Specimens A 1936 – A 1940, collected by Captain P. R. Lowe, R.A.M.C., in July, 1917, from the quarries near Wizerne, on the south side of the River Aa, near St. Omer. The matrix is a soft, friable, glauconitic sandstone, of a pale yellow colour. Among the associated fossils are internal casts of *Thracia* and of a *Pholadomya*, probably *P. konincki* (*fide* R. B. Newton). The map of the French Geological Survey applies the name Sables de Bracheux to this outcrop, but the fauna is not that of the type-locality. In some of the specimens the cancellate ornament is well defined, and in A 1939 the lines run diagonally (compare op. cit. p. 551, line 4 from end, and fig. 4).

The first point brought out in this note is the extended range in time of *Terebella cancellata* from Aptian to Thanetian.

The second point is the constant association of this form with a glauconitic facies and a fauna relatively rich in mollusca.

V.—Iceland—a Stepping-Stone.

By E. B. Bailey, M.C., B.A., F.G.S.

1. Introduction.

WHEN in 1897 Sir Archibald Geikie published his important monograph on the *Ancient Volcanoes of Great Britain* he devoted chapter xl to a description of Iceland—so largely does our North Atlantic neighbour bulk in the eyes of British vulcanologists.

Geikie drew the greater part of his information from Thoroddsen's writings, supplemented by those of Helland, Tempest Anderson, and Johnston-Lavis. His theme throughout was the conspicuous and abundant evidence afforded of fissure eruptions.

Since then various other publications have appeared dealing in English with the volcanic phenomena of Iceland. Of these we may mention three in particular:—

In 1901 Thoroddsen brought out his *Geological Map of Iceland* on the scale of 1 : 600,000. It is a truly magnificent achievement, representing much of its author's life-work in the field from 1881 onwards to 1898.

In 1909 Suess supplied further summaries of Thoroddsen's results, especially in regard to ring-fractures, cauldron-subsidences, and earthquakes. His descriptions, accompanied by two of Thoroddsen's small-scale maps, will be found on turning to vol. iv, p. 262, of the Sollas (English) edition of *The Face of the Earth*.

In the same year Clough, Maufe, and the present writer contributed a resumé of Spethmann's 1908 paper[1] on Askja, Iceland's greatest volcano. This short account is illustrated by Spethmann's own map, and starts on p. 666, vol. lxv (1909) of the Quarterly Journal of the Geological Society. Its intention is to facilitate comparison between the cauldron-subsidences of Askja, in Iceland, and of Glen Coe, in Scotland—Askja, of post-Glacial age, with its deep caldera and its rim-craters and solfataras; Glen Coe, of Lower Old Red Sandstone age, with its caldera form obliterated by erosion and its external ring of intrusions bared by the same agency.

Since Glen Coe was described much has been written by members of the Scottish Geological Survey on ring-fractures and ring-intrusions; notably by Maufe in relation to Ben Nevis, and by Wright, Richey, Clough, and myself in regard to Mull. As time goes by the value of a knowledge of Thoroddsen's observations in Iceland becomes more than ever apparent. Accordingly some years ago I prepared an abstract of "Die Bruchlinien Islands und ihre Beziehungen zu den Vulkanen",[2] a paper already referred to by Suess. This abstract, rearranged, forms Part 2 of the present communication. Part 3 is a definitely speculative venture, in which Suess is in large measure adopted as guide, though in certain important matters his conclusions are set aside.

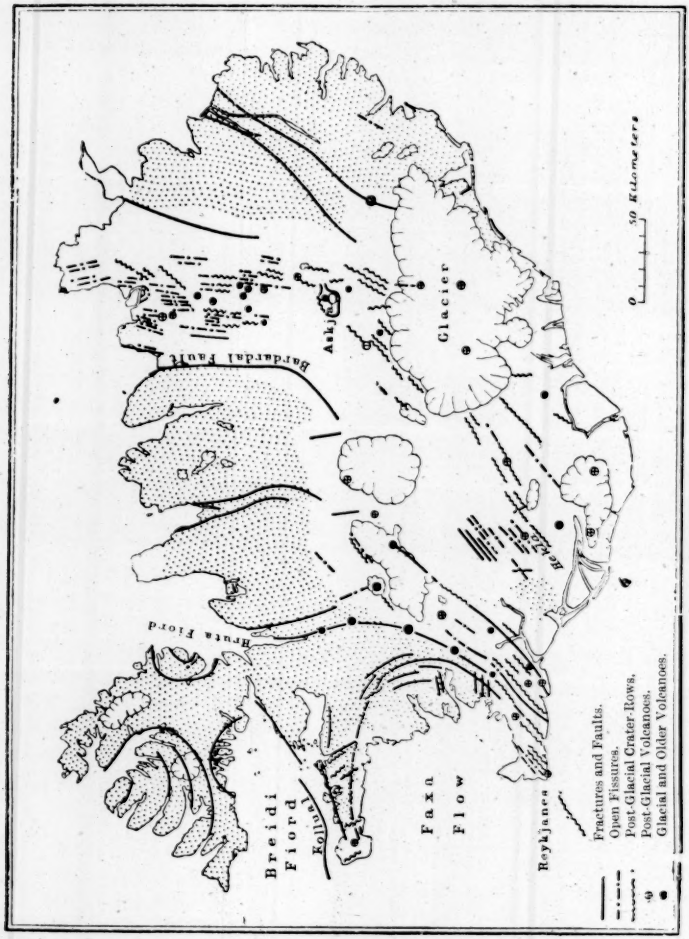
The map of Iceland, p. 468, is based essentially on Thoroddsen's 1905 map, somewhat reduced in scale, and with the earthquake districts and much of the topography omitted. The outcrop of the Older Tertiary Lavas is an additional feature derived from Thoroddsen's 1901 map. It should also be pointed out that Thoroddsen merely shows the Askja Caldera as a geographical feature, whereas in accordance with Spethmann's observations I have ventured to surround it by a ring-fault, with a minor subsidence indicated inside.

[1] "Vulkanologische Forschungen im östlichen Zentralisland": Neues Jahrb., xxvi, Beilage-Band, p. 381, 1908.

[2] Peterm. Mitth., Band li, pp. 49–53, with map and crater-plans.

2. Thoroddsen on Icelandic Fractures and Volcanoes.

Geologically, Iceland is divisible into two, an Old and a New. The Old is not continuous, but is separated by the New into an eastern and a western province. In Old Iceland basaltic lavas of early Tertiary date, comparable with those of Antrim and the



Iceland, after Th. Thoroddsen. The Early Tertiary Basalts are stippled. The more recent volcanic rocks, from the Pliocene Breccia Formation onwards, are left plain.

Hebrides, are everywhere exposed to view. In New Iceland these ancient lavas are concealed by widespread volcanic accumulations reaching down, in point of time, to our own day. The difference finds expression in many other ways than in the nature and age of the prevailing surface rock. As a volcanic district New Iceland is active, whereas Old Iceland is extinct.

The differentiation of the New Iceland from the Old seems to have been effected at the close of the Miocene Period, when the basaltic plateau developed fractures and began to sink. In Pliocene times numberless outbursts gave rise to a great bow of palagonite tuff and breccia, which, with its later associated lavas, is the country rock of New Iceland from coast to coast. Since then volcanic activity has been more or less continuous, always within the same restricted area: in late Pliocene times and probably also during the Glacial Period, extensive lava fields of dolerite were produced, followed throughout post-Glacial time, by widespread outpourings of basalt with very subordinate liparite; the post-Glacial basalts, considered by themselves, cover an area of little less than 11,200 sq. km.

Erosion has stripped Old Iceland of much of the spectacular accoutrements of vulcanicity. What meets the eye for the most part, is an immense pile of basalt flows dipping very gently inwards from either side towards the arcuate belt of tuff, breccia, and later lavas. Often, indeed, the early lavas are practically horizontal, more especially in the much-faulted coastal region lying between the Bardardal and Hruta Fiord Faults.

In some ways the most interesting feature of Old Iceland is the ring-fracture system (*Kreisbrüche*) of the north-west peninsula. There, lignites, clays, and leaf-beds, interbedded with the lavas, serve as valuable indices to the displacements the country has undergone. The lines of ring-fracture are sometimes marked by warm springs and parallel open cracks. And according to Suess, who evidently relies on the paper in which Thoroddsen elaborates his discovery, each ring-fault steps both the geology and the topography down towards the centre, while the intervening annular strips slope gently outwards towards the periphery.

In harmony with the ring-faults of the north-west peninsula are the cauldron-subsidences of Breidi Fiord and Faxa Flow.

The Snaefellsness Peninsula, separating these two great bays, is a horst, and consists mostly of old basalt, in part covered by the Breccia Formation and later basaltic lavas. It is cut by cross-faults locally depressing the old basalt platform below sea-level.

The sunken area of Breidi Fiord on the north, includes on its bottom a grabe called Kollual, 75 km. long and 9 km. broad. That of Faxa Flow, on the south, is bounded by faults, with a downthrow of 200–300 m., lined with hot springs and crater-rows. Faxa Flow is very liable to earthquakes, and altogether, both in its rocks and in its behaviour is perhaps in as close alliance with the New Iceland as it is with the Old. In Old Iceland, close fractures, faults, and lines of hot alkali springs occur, but not solfataras; while, except about Faxa Flow, earthquakes and glacial and recent volcanoes, including crater-rows, are rare. In New Iceland, gaping fissures, graben, and solfataras (with subordinate alkali springs) are all common; so too are earthquakes, crater-rows, and big volcanoes.

There are five earthquake districts in Iceland. All border the coast, and all, save Faxa Flow, belong to New Iceland.

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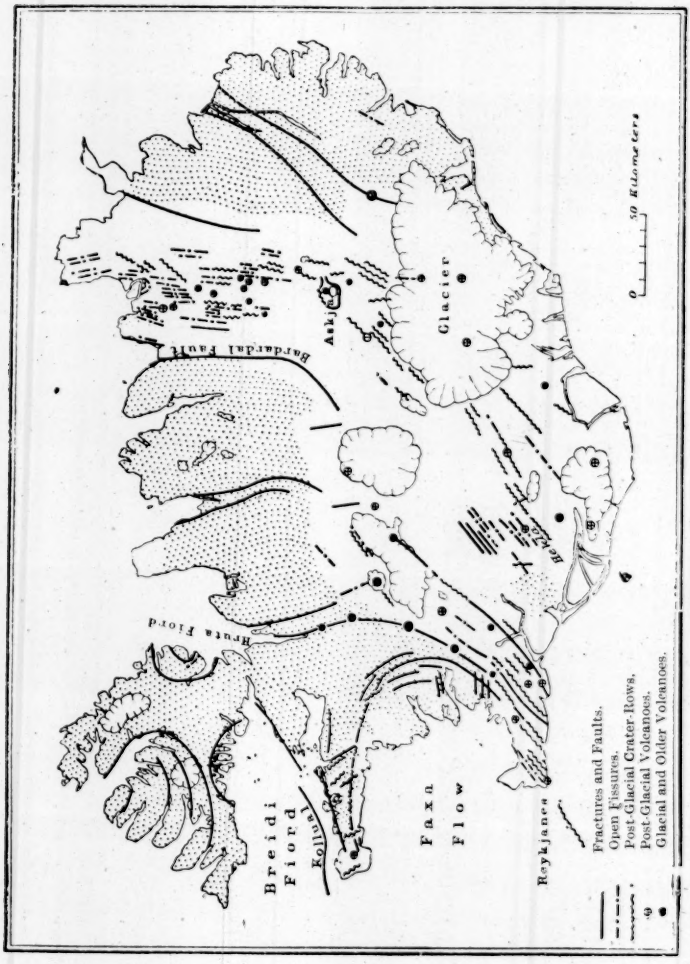

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other direction, east from the base of the Reykjanes Peninsula, is a particularly complex field of subsidence and unrest. The district is broken into segments which behave independently during earthquakes, the while the great neighbouring volcanoes stand passively indifferent. Far away on the northern coast are three more earthquake districts. In the interior highlands earthquakes are rare unless in obvious connexion with volcanic activity.

The boundaries of New Iceland now deserve attention. The western margin, where not concealed by superficial accumulations, is seen to be largely determined by two arcuate faults, each with a downthrow towards the convex eastern side. The opposite margin is less definite, for here the early Tertiary lavas dip gently beneath the Breccia Formation. Of the two border-faults on the west of New Iceland the outer one is the older. It runs from the Reykjanes Peninsula northwards to the Hruta Fiord. Its course is marked by the ruins of great extinct volcanoes. The inner fault, known as the Bardardal Fault, first originated after great areas had been covered beneath post-Breccia dolerite lavas. The boundary of New Iceland where it runs east and west between the Hruta and Bardardal Faults is very obscure owing to its being hidden beneath glacial and similar surface deposits.

The topographical character of New Iceland is distinctive in the extreme. Every feature in the north runs from north to south, and in the south from north-east to south-west. This is all due to the course taken by volcanic fissures, too numerous for individual representation on a map. Many parts of the district, lowland and highland, are literally striped by them.

Often lava-flows cut by the fissures have undergone considerable subsidence. Near the head of the northern branch of the long inlet east of the Reykjanes Peninsula, an old subsidence 60–70 sq. km. in extent, and 30–50 m. in depth between two fissures known as Almannagja and Hrafnagja, sunk two or three additional metres during a violent earthquake in 1789. Of more recent date and more considerable magnitude are certain graben of the Odadahraun—the district neighbouring Askja—where, in one instance a fault-scarp 30–40 m. high continues for a distance of several kilometres.

In two instances fissures which have yielded lava, remain open and craterless; Eldgja, one of the two, in a single outburst yielded 9 c.km. of lava. But almost always a crater-row has been erected along the course of an active fissure. Such rows extend sometimes from 10 to 35 km. The craters vary greatly in form: they may be elongated, or they may have one ring within another, or one wall collapsed, the other standing. Their height is commonly from 10 to 200 m.

A fissure sometimes continues open for as much as 15 km. at a stretch. Looking down into it one generally notices water or snow. It is difficult to separate the non-volcanic from the volcanic, for many a fissure of non-volcanic aspect where first encountered is found to have poured out lava at some other part of its course. Small parallel fissures without volcanic activity often accompany the more important volcanic fissures.

Generally a fissure is only used once, but the well-known Laki fissure, with its crater-row dating from 1783, carries upon itself a crater of prehistoric age.

Most of the volcanic fissures are not accompanied by faulting, though this is a rule to which there are numerous exceptions. Two more examples may be quoted.

One of a series of graben occurring 25 km. east of Myvatn—north of Askja—had for a time fault-scarps 10–20 m. high, 15 km. long, and 400–500 m. apart. During a great earthquake in 1875 lava rising along the western wall, filled this depression. Then a crater row 22 km. long was developed, and poured out 300 c.km. of lava. The Ögmundarhraun lava in the neighbourhood of Krisuvik—east of Reykjanes—is also interesting in this connexion. It issued in 1340 from two parallel fissures. The southern part of the strip between these fractures has sunk 66 m. since the beginning of the outflow, and on the western wall overlooking the subsidence are the halves of four bisected craters of which the corresponding halves have been carried downwards.

A major fault has not always located the volcanoes of its neighbourhood. These are often situated on parallel fractures, *especially on the upthrow side of the great dislocation.* I have ventured to italicize the foregoing statement, as it is so reminiscent of the distribution of the intrusion which rose along the fault boundary of the cauldron subsidence of Glen Coe. The Icelandic examples chosen by Thoroddsen to illustrate this tendency are as follows :—

For 50 km. a fracture reaches from Krisuvik (east of Reykjanes) to Hengill, where the northern side has sunk 200–300 m. Parallel with it on the upthrow side is a wonderfully continuous system of crater-rows borne on subsidiary fractures. A similar case occurs on the south side of the Snaefellsness Peninsula overlooking Faxa Flow. Here too the craters are mostly on the upthrow side.

At the same time Thoroddsen does not wish to emphasize this point. In the Odadahraun, craters mostly occur on the margins of horsts. In Myvatn, farther north, the marginal position recurs, though other crater-rows are found upon the mountain horsts. What is clear about the distribution of contemporary vulcanicity in Iceland, viewed as a whole rather than in detail, is that it characterizes a great field of subsidence—to which in the present summary the name New Iceland has been assigned.

Choked eruption-fissures and the ruins of major volcanoes persist from Tertiary and Glacial times, but crater-rows of any but post-Glacial age have been dismantled. The following statistics refer solely to post-Glacial occurrences of various types of volcanoes. Thoroddsen has counted 87 major eruption-fissures with their attendant strings of craters; 6 strato-volcanoes (Vesuvius type); 16 lava-domes (Kilauea type); 13 explosion craters and crater-groups (Puy type); 2 sub-Glacial outbursts. Of these 130 post-Glacial volcanoes 25–30 have been active during historic times.

The accumulation of material that goes to make up a great volcano, whether of the Vesuvius or Kilauea type, often renders the original dependence of the volcano upon a fissure a matter of hypothesis

rather than of observation. This cannot be said, however, of the strato-volcano Hekla (1,557 m. high), which extends 27 km. parallel to the local fissures, and only 2–5 km. at right angles to them. Regarding the Kilauean domes, where the difficulty of interpretation is admittedly great, Thoroddsen summarizes his position as follows: "The geological evidence shows above all that the Icelandic domes have been built on fissures where the eruption canal has been opened so wide as to give unimpeded egress to the lavas." Askja, with its caldera 55 sq. km. in extent, he points out, is situated at the crossing of two major fissure-systems; and he indicates on his map that its caldera is margined to some extent by a crater-row (Spethmann on his large-scale map shows additional rim-craters and solfataras). He further mentions an explosion-crater as having arisen on an obvious open fissure near the edge of a considerable subsidence which in 1875 affected about a quarter of the bottom of the Askja Caldera.

The 1875 eruption at Askja, and another of earlier date, 1724, at Viti, are the only two known to have given rise to explosion craters during historic times. Both eruption centres produced nothing but ash; but the relief of pressure in each case seems to have upset the equilibrium of neighbouring districts, leading to great subsidence and fissuring, and to an immense outpouring of lava.

Viti enjoys the rare distinction of being to all appearance unconnected with any fissure that has reached the surface. It has built but a small cone, so that the surrounding country is open to observation.

3. Suess on Lunar Craters and Terrestrial Arcs.

In the paper already referred to, read before the Geological Society of London, Clough, Maufe, and the present writer suggested an analogy "between the Glen Coe cauldron of Old Red Sandstone times, with its girdle of fault-intrusion, and the Pacific Ocean of to-day, with its fringe of marginal volcanoes". The source of inspiration is not far to seek. While we were mapping in Glen Coe we felt as though we were reading Suess again, and that our discoveries had already been in large measure described in vol. i of that author's masterpiece.

Naturally, on the appearance of vol. iv of the Sollas edition of *The Face of the Earth*,[1] we turned with keen anticipation to those passages in which Suess develops his earlier conceptions of cauldron-inbreaks and arcuate structures in general. We found there an introduction to Thoroddsen's work on the ring-fractures of Iceland, dealt with in Part 2 of this communication, and also much additional matter which serves as the basis of the discussion that follows.

After recalling how, at the conclusion of vol. i, he had already

[1] The many page references that follow all refer to this volume. In its footnotes the original sources may often be traced. For additional information, including several very helpful illustrations, the reader may advantageously consult the corresponding parts of tome iii of the de Margerie edition, *La Face de la Terre*.

stated that the oceanic basins of the earth originate and increase through subsidence and inbreak, Suess turns his attention to the "seas" and craters of the moon, and suggests that Iceland with its ring-fractures and cauldron-subsidences may furnish us with a true conception of the lunar surface (p. 598). He develops this comparison in some detail, and then passes on, as one might expect, to Southern Italy, and claims the Calabrian earthquakes as marking the growth of a caldera of lunar type under our very eyes, with the Lipari volcanoes at its centre and Etna on its periphery.

Suess also refers (p. 595) to a well-known tendency of major craters of the moon to carry minor craters "riding" upon their margin—as Etna may be said to ride upon the Calabrian cicatrice. He suggests that this riding on the ancient rampart may be accounted for as a result of peripheral fissuring. His terrestrial analogues he derives from Italy; but, had he known, he might have pointed once more to Iceland, to the rim-craters of the Askja Caldera; or he might have invoked the aid of Scotland, and interpreted the riding craters as the surface manifestation of ring-dykes of the kind now known to occur at Glen Coe, Etive, Ben Nevis, and Mull.[1]

It appears from what Suess says that he had no hesitation in classifying together cauldron-subsidences of the most diverse dimensions. On the one hand, he compares the cauldron-subsidences of Iceland with certain sinkings which have followed in mining districts upon the extraction of salt, or the draining of a substratum of quicksand (p. 264); on the other hand, he links them with lunar craters and with depressions of oceanic extent, whether lunar or terrestrial—although admittedly with increased extent the circular form tends to disappear (p. 598).

This grouping of large and small may be quite mistaken, but it is likely to be accorded a very general sympathy. The most diminutive of the phenomena chosen by Suess for comparison is a series of arcuate fissures found by him in an asphalt pavement which was sinking differentially as compared with its curbstone (p. 503). "The subsidences of the asphalt pavement take place," he says, "on the concave side of each of the several arcuate fragments. . . . A similar process seems to have occurred in the north-west of Iceland." One should not forget, however, that important exceptions are afforded along the western margin of New Iceland, where Thoroddsen finds the downthrow on the convex, and not the concave, side of the boundary faults.

Leaving Suess for a minute it may perhaps be profitable to draw attention to other instances of what appear to be ring-fractures on a small scale. About 3 per cent of the older cracked picture surfaces of a collection such as that of the National Gallery in

[1] The investigation of these occurrences has been among the happy duties of the Scottish Geological Survey. Those mainly employed on the work have been H. B. Maufe, C. T. Clough, H. Kynaston, W. B. Wright, J. E. Richey, and myself. Many of our results are given in two Survey publications, *The Geology of Ben Nevis and Glen Coe* (1916) and *Summary of Progress for 1914* (1915).

London show very well-defined groups of circular fractures. They occur in concentric systems side by side with the more usual irregular cracks of the type known to geologists as suncracks—from their frequent development in drying clay. Circular fractures play a much greater rôle in the general crack system of less carefully guarded canvases. In fact, almost every out-of-door painted canvas, or linoleum, carrying a notice or advertisement, or stretched to cover a tradesman's cart, shows circular fractures at one place or other of its surface. Perhaps these fractures are analogous to the circular cracks of a broken pane of glass, and in any case great care should be taken in their interpretation. Indeed, they may not deserve the name of ring-fracture at all. A ring-fracture in geology follows a more or less cylindrical surface, and it should be remembered that quite other fractures, better styled cone-fractures, have an equally marked tendency to arcuate outcrop. Cone-fractures are now well known through Harker's work on the inclined sheet system of Skye and the later researches of others on the analogous systems of Mull. But returning from this digression, let us recall the most numerous ring-fractures of recent times. They originated in concentric systems within and about shell-craters, when the impalpable dust of the inner slopes contracted, and no doubt at its lower levels flowed, after its first wetting by a shower of rain.

The occurrence of arcuate volcanic fractures in Iceland, sometimes with a great radius of curvature and determining the site of major volcanoes, seems to lead naturally to a comparison with other volcanic arcs such as that of the Aleutian Isles. But Suess does not follow this line of approach. For him Icelandic arcs are a phenomenon of subsidence, whereas the mountain arcs, with which he classes the Aleutian Isles, are a phenomenon of lateral compression. I venture to think that if he had lived much longer he would have claimed a community of origin for the two systems of arcs. His ideas in this connexion seem to have been undergoing evolution as he wrote.

Early in his scientific career Suess started out to study the development of the Alps. He travelled far, and, though outstripped as time went on by certain of his comrades, he had good reason to be content. He could afford to let others struggle on towards the coveted summits of Alpine interpretation, while he lingered at a lower level; for he had learnt to use the writings of others as an astronomer uses a telescope, and through them to gaze upon the face of the earth from chosen vantage points, and thus to enrich two generations of geologists with a wisdom and knowledge gathered from every corner of the globe.

It is not surprising that at first he should regard the arcuate form of the Alps as a combined result of push and obstruction. Nor is it surprising that at first he should think of the Alps as typical of the other arcuate chains of the earth's surface, and extend his conception of push and obstruction to account for the configuration of the whole class.

If, like Darwin, he had learnt his geology on the borders of the Pacific Ocean he might well have had quite a different outlook in this particular. And as it is he seems to have turned increasingly to the

Pacific ranges for information regarding the essential features of arcuate mountain chains. The account he gives of them can best be realized by reproducing certain of his statements.

"Three arcuate and concentric elements occur in the Asiatic island festoons, namely, the foredeeps, the folded chains (cordilleras), and the volcanic lines" (p. 504).

In the Bonin Islands of the Pacific, concentric zones are recognized as follows:—

1. Foredeep.
2. Tertiary belt, often folded.

3*a*. Folded cordilleras, the innermost sometimes backfolded.

3*b*. The volcanic arc "*always in the cordillera, and more precisely in the zone of forefolding*, never in that of backfolding, and never in the foredeep.

"The same structure is also present in the Northern Antilles, but in these islands no cordilleras occur within the volcanic zone. In general, the cordilleras are the first to show a tendency to disappear, as may be seen in the Bonin islands, while the volcanos hold their ground with great tenacity as in the Aleutian islands" (p. 516).

"As a result of these comparisons we see that the North Antilles (probably also the South Antilles), the Alaskides and all the island festoons as far as the Philippines, the Oceanides also, and in Asia the oppositely-curved Burman arc, present a similar structure, and this structure, although less sharply defined, is also perceptible in the southern marginal arcs situated in great part on the mainland.

"The constant occurrence of the arc of active volcanos within the zone of forefolding is a remarkable fact" (p. 524).

It is not only in his descriptions of mountain chains that Suess seems to contradict his old theory. We have already referred to his observations regarding certain arcuate fractures developed during the partial subsidence of an asphalt pavement under conditions wherein tangential pressure played no part whatsoever. As stated above, he compares these arcuate fractures with those of Iceland, but he is obviously more interested in their reproduction of the phenomena of *linking* and *syntaxis*, so characteristic of the mountain systems (p. 503); moreover, he returns to their consideration when he discusses the origin of foredeeps (p. 505).

And yet his views in regard to the cause of the arcuate form of the various elements of mountain ranges do not seem to have altered. The arcuate mountain fronts he compares with certain moraines described from Greenland, where inland ice, forcing its way between nunataks, sometimes carries ground moraine up from the bottom, and spreads it in arcs over ice in front, acting the part of foreland (p. 528); and the foredeeps, he says, "are subsidences of the foreland beneath the folded mountains" (p. 295).

The difficulty of this theory is that it gives scant recognition to the volcanic arc, the Cinderella of the piece. Other workers, less acquainted with the Alps, have held that the line of volcanoes and its frequent underground equivalent in the denudation series, the line of batholiths, must be afforded a very prominent position in any interpretation of mountain structure. The references that might be

given in this connexion are legion, among them chapters vi and ix of Daly's recent book *Igneous Rocks and their Origin* (1914). It is not intended here to make a general survey of the subject, but rather to sketch certain conclusions which seem to follow naturally from Suess's presentation of this phase of world geology. The main suggestions offered are as follows:—

1. The arcuate form characteristic of many of the great mountain chains can scarcely have originated through forward movement of these chains, since it characterizes the Aleutian Isles, and other typical examples, where the occurrence of forward movement has been denied.

2. Iceland, with its volcanic arcs, large and small, may well supply a stepping-stone between arcuate fractures of the type so familiar in Scotland, with their accompaniment of ring-dykes, and the vastly greater Aleutian Arc, with its serial volcanoes.

3. The development of volcanic arcs suggests tension rather than compression. The arcuate fractures of an asphalt pavement, the circular cracks of a painted canvas, the miniature landslip fissures on the slopes of a shell crater, all support this contention.

4. Arcuate fractures have often served as guides for the uprise of igneous magma. Volcanic accumulation is the surface manifestation; batholithic intrusion the corresponding subterranean phenomenon.

5. Where, as in Iceland, the magma has been predominantly basaltic, its mobility has favoured volcanic expression. Where, as in the American cordilleras, a vast supply of granitic magma has been drawn upon, or developed, its viscosity has determined intrusion on a magnificent scale. The date and manner of origin of the granite is not involved.

6. The association of a folded cordillera with a volcanic arc suggests the collapse of an unconsolidated axial batholith—a closing together of its two walls and a corresponding compression of its roof. By analogy the same suggestion holds even where the volcanic arc is absent.

In polar regions the cooling of an ice-flow often leads to a development of tension-cracks. Into these, sea-water rises to be frozen over at the surface. A return of warm weather brings the walls together, and the roof of the temporary fissure is driven up to form a ridge. The analogy between such a ridge and the Alps, though obviously very imperfect, seems to merit a passing notice.

7. The cause of a batholithic collapse need not be strictly local. At Kilauea the solid floor of the crater, after ascending gradually for years, will suddenly subside a thousand feet or so, in the course of a few days. On occasion a volcanic outburst at some point on the island accompanies this subsidence, but at other times nothing of the kind is seen, and a submarine eruption is postulated. Perhaps the outpourings of lava in the Brito-Icelandic province had a share in the upheaval of the Alps.

8. Once folding and thrusting have been developed, the outline and almost every other feature of the mountain arc must be profoundly modified. There is not only the revolution in what may be termed the home country of the chain, but also the concomitant

invasion of neighbouring territories, often on a truly grandiose scale.

9. Obstruction must be admitted as an additional factor in determining the form of a folded range. There may be much truth in the statement that several arcs of the Jura Mountains press forward into the gap furnished by the subsidence of the Rhine "like waves into a bay" (p. 526).

10. Subsidence of a foredeep may, in many cases, have resulted in part from the advance of the cordillera. Or it may, on the other hand, have helped to guide such advance. It is well to remember, however, that at present the Andes are interpreted as furnishing an illustration of back-folding turned eastwards, away from the long belt of subsidence which seems to merit the designation foredeep (p. 497). And also that central subsidences are claimed in well-known cases, such as that of the Lombardy Plain, to which Salomon ascribes the peripheral uprise of the tonalite of Adamello (p. 560).

VI.—Some American Papers on Volcanoes.

"The Present Condition of the Volcanoes of Southern Italy," by H. S. Washington and A. L. Day. Bull. Geol. Soc. America, vol. xxvi, pp. 375–88, 1915.

A study of the conditions prevailing at Vesuvius, Etna, and the Æolian Islands in the summer of 1914.

Puff Cones on Mount Usu," by Y. Oinouye. Journ. Geol., vol. xxiv, pp. 583–6, 1916.

The writer watched the eruption of July–August, 1910, and paid several later visits. He describes puff-cones formed on mud-flows from small craterlets: they developed about a year after the eruption and are attributed to escape of gas.

"An Unusual Form of Volcanic Ejecta," by W. E. Pratt. Journ. Geol., vol. xxiv, pp. 450–5, 1916.

A description of concretion-like bodies found in the ash of the Taal volcano, Luzon, in February, 1911. They appear to have been formed by the coalescence of dust and water vapour in the air, forming mud-balls, and may be described as "volcanic hailstones".

"Notes on the 1916 Eruption of Mauna Loa," by H. O. Wood. Journ. Geol., vol. xxv, pp. 322–36 and 467–88, 1917.

An amplification and correction of earlier observations, giving a large amount of detail as to the special features of this eruption, which included an outburst of fumes followed by lava-flows.

"Activity of Mauna Loa, Hawaii, December–January," 1914–15, by T. A. Jaggar, jun. Amer. Journ. Sci., vol. xl, pp. 621–39, 1915.

An amplification and revision of a previous paper, with a description of an ascent of Mauna Loa and the phenomena observed. It is concluded that this outbreak was a preliminary summit-ebullition of an eruptive period.

"Explosive Ejectamenta of Kilauea," by S. Powers. Amer. Journ. Sci., vol. xli, pp. 227–43, 1916.

Ash deposits are found on the flanks of all the volcanoes of Hawaii. Those of Kilauea represent two eruptive periods, one prehistoric, the younger dating from 1789. The products of the latter consist of bombs, ash, and "thread-lace" scoria, this being the extreme phase of pumice, lava froth carried by the wind.

"Effects in Mokuaweoweo of the Eruption of 1914," by H. O. Wood. Amer. Journ. Sci., vol. xli, pp. 383–408, 1916.

A description of the effects in the summit crater of Mauna Loa of the eruption of November–December, 1914, as observed on three ascents. Maps and photographs are given, showing the changes produced by this outbreak.

"Volcanological Investigations at Kilauea," by T. A. Jaggar, jun. Amer. Journ. Sci., vol. xliv, pp. 161–220, 1917.

The writer recognizes two types of lava in Halemaumau pit; bench magma, which is the main filling of the lava column, and lake magma, which fills saucers and shafts. The former is a product of solidification above normal viscosity, the latter is liquefied below normal viscosity. Measurements of the temperature of the lava are recorded.

"The Lava-flow from Mauna Loa, 1916," by T. A. Jaggar, jun. Amer. Journ. Sci., vol. xliii, pp. 255–88, 1917.

A very detailed description of the lava-flow of May, 1916, which brought to a close the eruptive period of 1914–16. Diagrams are given summarizing the relations of the outbreaks to local seismicity and to the fluctuations of the lava-level in Kilauea. Mauna Loa and Kilauea are believed to be connected as correlated gas vents and not as hydrostatic siphons.

"A Few Interesting Phenomena in the Eruption of Usu," by Y. Oinouye. Journ. Geol., vol. xxv, pp. 258–88, 1917.

After a preliminary earthquake phase, explosions gave rise to mud-flows, which later developed puff-cones. Marked changes of level occurred in the neighbourhood, and an increase in the height of the cone is attributed to the upthrust of a spine or dome.

"The Active Volcanoes of New Zealand," by E. S. Moore. Journ. Geol., vol. xxv, pp. 693–714, 1917.

There are five more or less active volcanoes, namely, White Island, Tarawera, Ruapehu, Ngauruhoe, and Tongariro, lying along a great N.E.–S.W. fissure. These are described in general terms, with a special account of the eruption of Tarawera in 1886.

"Physiographic Development of the Tarumai Dome in Japan," by H. Simotumai. Amer. Journ. Sci., vol. xliv, pp. 87–97, 1917.

A description, with maps, photographs, and drawings, of the dome formed in April, 1909, which is taken as the representative specimen of its type.

CORRESPONDENCE.

RECENT PAPERS ON THE DURHAM COALFIELD.

SIR,—In the GEOLOGICAL MAGAZINE of July there is a letter from Mr. J. T. Stobbs criticizing two papers which appeared in the April and May numbers. I desire to give a short reply to this letter. The chief reason for publishing the paper dealing with the borings at Cotefield Close and Sheraton was that the cores gave information regarding an almost totally unknown facies of the Middle Magnesian Limestone, and therefore more stress was laid on the description of the Permian rocks than on those of the Coal-measures, which were only dealt with in a general manner. It may, however, be possible to deal with these and other sections in the latter strata on a subsequent occasion. I came to the conclusion after consultation with the mining engineer that the boring at Cotefield Close had entered the Coal-measures beneath the Brockwell Seam from comparison with other sections, from the character of the strata and from the structure of the country. It is true that the coals in the Ganister Series have been worked in the western part of the coalfield, but over a large portion of it the exact nature of the strata occurring beneath the Brockwell Seam are not well known. The coal-seams in these beds are not constant, are thin, and seldom worked. There are a few borings in the Ganister Series, but the strata have never been properly correlated or described. The late Professor Lebour wrote some years ago, "As a consequence of the small importance of the coal-seams known to exist in the Ganister Beds not many detailed sections of sinkings and borings can be referred to for details in the strata." These words are still true and especially true for the deeper parts of the coalfield beneath the Magnesian Limestone of Durham. Further, from a palæontological standpoint, not only the Ganister Series but the whole of the Coal-measures of Northumberland and Durham may be said to be little known. No exact knowledge of the zones in this coalfield has yet been obtained. *Aviculopecten* (*Pterinopecten*) *papyraceus*, *Carbonicola robusta*, and *Anthracomya Phillipsi* appear to be confined to definite horizons, but there still remains much work to be done on the palæontology of these rocks. I think that when the Coal-measures of the Northern Coalfield are zoned it will be found that *Aviculopecten papyraceus* is confined to the Ganister Series in this area. My note regarding it may not be found to be so quaint as Mr. Stobbs supposes. I used the generic name *Aviculopecten* because I was referring to Professor Lebour's discovery of this fossil. If Mr. Stobbs knows anyone who is thoroughly acquainted with the Ganister Series of Northumberland and Durham and could prevail upon him to write an account of these beds I am sure geologists would feel indebted to him.

In the paper "The highest Coal-measures in the Durham Coalfield" an attempt was made to give an exact description (which had never been done) of the section in which *Anthracomya Phillipsi* occurs; also to show the relation of *Ancylus Vinti*, Kirkby (*Carbonicola Vinti*, Hind), to *Anthracomya Phillipsi* as they occur associated together in this section, and to give as complete a list of the fauna and flora as possible. Dr. Trechmann and I certainly never thought